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Volume 27: Natural Background Radiation

Science Applications, Inc.
P.O. Box 2351
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1 July 1980

Final Report for Period 1 January 1976—30 June 1979

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The Natural Background Radiation Module computes the Earth's natural upwelling spectral radiance (from 2 to 5 μm) by averaging over paths in an Earth-tangent cone with vertex at each selected altitude. The processes contributing to the radiance are emission from air, Earth's surface, and clouds and reflection of solar radiation from Earth's surface and clouds; attenuation is by molecules and aerosols. The Module integrates ROSCOE-IR models for (a) atmosphere, (b) atmospheric thermal emission, (c) molecular

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20. ABSTRACT (Continued)

transmittance, (d) aerosols, (e) clouds, (f) Earth's surface characterization and radiance, (g) solar radiation, and (h) upwelling natural radiation. Models (f), (g), and (h) are documented fully herein; other models (three of which were developed by other organizations) are documented here mainly in terms of functions performed, inputs, and outputs. The user selects the modeled Earth's surface from one of seven categories (with possibly an associated descriptor): (1) Lambertian surface (and diffuse reflectance), (2) wind-ruffled water (and wind speed), (3) snow (and its age parameter), (4) sand, (5) soil, (6) foliage, and (7) urban material (and degree-of-urbanization parameter).

Conversion factors for U.S. customary to metric (SI) units of measurement.

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 X E -10
atmosphere (normal)	kilo pascal (kPa)	1.013 25 X E +2
bar	kilo pascal (kPa)	1.000 000 X E +2
barn	meter^2 (m^2)	1.000 000 X E -28
British thermal unit (thermochemical)	joule (J)	1.054 350 X E +3
calorie (thermochemical)	joule (J)	4.184 000
cal (thermochemical)/cm^2	mega joule/m^2 (MJ/m^2)	4.184 000 X E -2
curie	*giga becquerel (GBq)	3.700 000 X E +1
degree (angle)	radian (rad)	1.745 329 X E -2
degree Fahrenheit	degree kelvin (K)	$t_K = (t°f + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E -19
erg	joule (J)	1.000 000 X E -7
erg/second	watt (W)	1.000 000 X E -7
foot	meter (m)	3.048 000 X E -1
foot-pound-force	joule (J)	1.355 818
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 X E -3
inch	meter (m)	2.540 000 X E -2
jerk	joule (J)	1.000 000 X E +9
joule/kilogram (J/kg) (radiation dose absorbed)	Gray (Gy)	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E +3
kip/inch^2 (ksi)	kilo pascal (kPa)	6.894 757 X E +3
ktap	newton-second/m^2 (N-s/m^2)	1.000 000 X E +2
micron	meter (m)	1.000 000 X E -6
mil	meter (m)	2.540 000 X E -5
mile (international)	meter (m)	1.609 344 X E +3
ounce	kilogram (kg)	2.834 952 X E -2
pound-force (lbs avoirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N·m)	1.129 848 X E -1
pound-force/inch	newton/meter (N/m)	1.751 268 X E +2
pound-force/foot^2	kilo pascal (kPa)	4.788 026 X E -2
pound-force/inch^2 (psi)	kilo pascal (kPa)	6.894 757
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 X E -1
pound-mass-foot^2 (moment of inertia)	kilogram-meter^2 (kg·m^2)	4.214 011 X E -2
pound-mass/foot^3	kilogram/meter^3 (kg/m^3)	1.601 846 X E +1
rad (radiation dose absorbed)	**Gray (Gy)	1.000 000 X E -2
roentgen	coulomb/kilogram (C/kg)	2.579 760 X E -4
shake	second (s)	1.000 000 X E -8
slug	kilogram (kg)	1.459 390 X E +1
torr (mm Hg, 0° C)	kilo pascal (kPa)	1.333 22 X E -1

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s

**The Gray (Gy) is the SI unit of absorbed radiation.

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74," American Society for Testing and Materials.

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SECTION 1

INTRODUCTION AND OVERVIEW

The Natural Background Radiation (NBR) Module is defined to be a computer program which integrates nine ROSCOE-IR models (see Table 1-1) into a consistent, stand-alone module for the purpose of developing and testing the capability to compute the natural upwelling spectral radiance as a function of altitude. The relationships of the routines in the NBR Module should be similar to the relationships of the routines in the ROSCOE-IR Program except for its use of overlays and a broader use of the GRC Dynamic Storage Allocation (DSA) System [SP-78].

The upwelling radiance will normally be a function of direction; however, for the anticipated applications it is expected that a spatially-averaged value will be adequate. (If later studies show that direction-dependent values are required, relatively minor code changes can be made to retrieve the more detailed information now generated to derive the spatially-averaged value.)

Computation of the upwelling radiance may be described with the aid of Figure 1-1. Point V is at altitude z above a selected reference origin,

Table 1-1. Models Integrated into the NBR Module.

Title	Model Number	Developer	ROSCOE Manual Volume Number
Ambient Atmosphere	1a	SAI/LJ	14a-1, 14c
Atmospheric Aerosols	1c,19:1c	VI	25
Natural Clouds	1d,19:1d	SAI/PA	24
Atmospheric Thermal Emission	20b	GET	28,31
Molecular Transmittance	24d	GET	28,31
Earth Surface Characterization	23a	SAI/LJ	27,Sect.2,3
Earth Surface Radiance	23b	SAI/LJ	27,Sect.5
Upwelling Natural Radiation	23c	SAI/LJ	27,Sect.6
Solar Radiation	23e	SAI/LJ	27,Sect.4

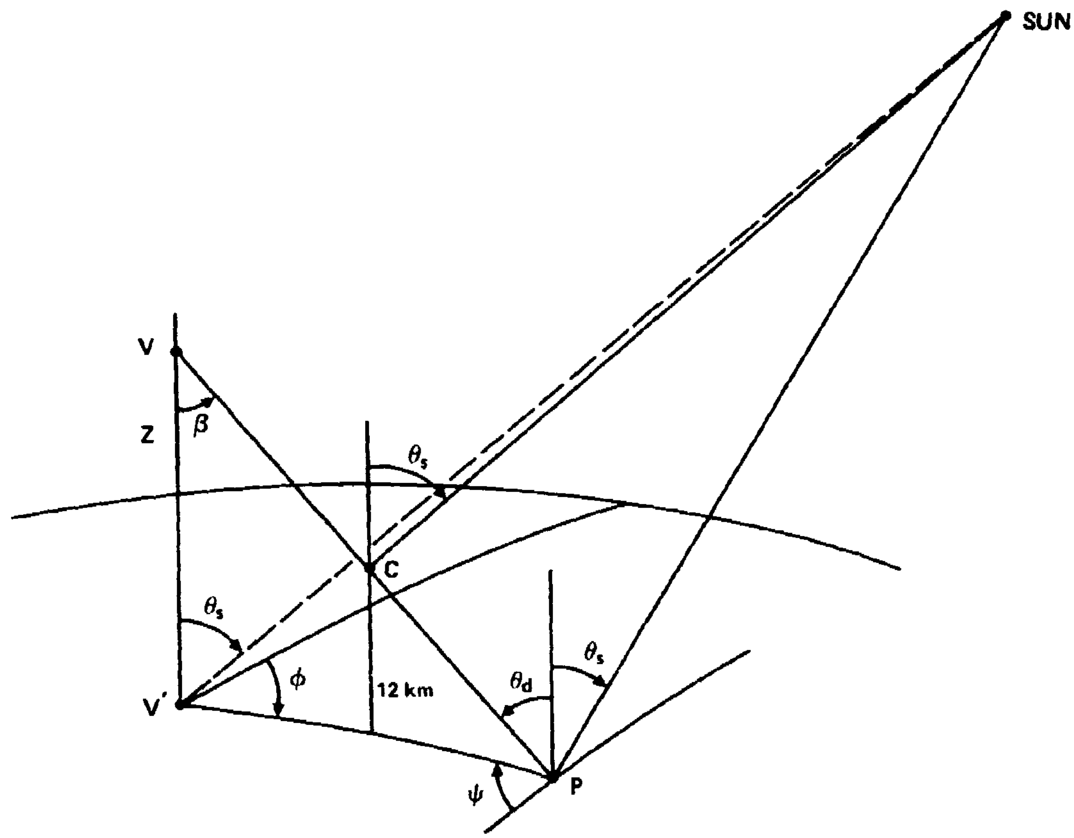


Figure 1–1. Geometry to illustrate the computation of upwelling natural radiation for one viewing direction $\overrightarrow{VP}$.

V'. For a (fictitious) detector at Point V viewing in the direction of Point P on the ground, the processes we include in computing the radiance in the direction of $\overrightarrow{PV}$ may be separated into two cases:

A. No Clouds

1. Air emission between V and P, attenuated by molecules and aerosols.
2. Surface emission at Point P (from any of the seven modeled surface materials), attenuated by molecules and aerosols along $\overrightarrow{PV}$.

3. Surface-reflected solar radiation, attenuated by molecules and aerosols along the total path ($\overrightarrow{SP} + \overrightarrow{PV}$).

B. With Clouds

(Highest cloud tops are at or below Point C at 12-km altitude. The first three processes below are weighted by the probability the line-of-sight along $\overrightarrow{VC}$ intercepts clouds.)

1. Air emission between V and C, attenuated by molecules and aerosols.
2. Surface emission from cloud tops at or below 12 km, attenuated by molecules and aerosols along $\overrightarrow{CV}$.
3. Cloud-reflected solar radiation, attenuated by molecules and aerosols along the total path ($\overrightarrow{SC} + \overrightarrow{CV}$).
4. Processes 1 and 2 from the no-cloud case, weighted by the probability of a one-leg cloud-free line-of-sight along $\overrightarrow{VP}$.
5. Process 3 from the no-cloud case, weighted by the probability of a two-leg cloud-free path along the broken path ($\overrightarrow{VP} + \overrightarrow{PS}$).

In view of the above-listed contributions to the radiance, it is easy to recognize the need for integrating so many models into the NBR Module. Five of these models, as indicated in Table 1-1, have been reported in other volumes. The remaining four models are documented in this volume. To this documentation we first provide an overall guide, followed by more detailed descriptions.

The Earth Surface Characterization Model is described in Sections 2 and 3. Section 2 contains general information and details for non-water surfaces; the details for water surfaces are given in Section 3. The Solar Radiation Model is described in Section 4 and the Earth Surface Radiance Model in Section 5. In terms of such models, the Upwelling Natural Radiation Model is presented in Section 6 and overall coding information for the stand-alone NBR Module in Section 7.

In Sections 2 and 3 we present the ROSCOE-IR model (23a) for the Earth surface characterization, in the spectral range from 2 to 5 μm (or 5,000 to 2,000 cm^{-1}). The principal routine in the model is Subroutine ESURF which

(with auxiliary routines for water surfaces) provides the (1) monochromatic bidirectional reflectance-distribution function (BRDF), monochromatic directional emissivity, and (3) temperature of the Earth's surface at the intersection point of the optical line-of-sight. Since the surface category is not automatically correlated with the geographic position, the user must select one of the seven categories provided plus an associated descriptor where appropriate: (1) Lambertian surface (and diffuse reflectance), (2) water (and wind speed), (3) snow (and its age-parameter), (4) sand, (5) soil, (6) foliage, and (7) urban material (and degree-of-urbanization parameter). The user calls Subroutine ESURF with the zenith angle of the solar ray at the intersection point, the direction of the detector at the intersection point (specified by the zenith angle and the azimuth angle relative to the principal plane of the solar ray), the altitude at the intersection point, the surface material (and associated descriptor) at the intersection point, and the wavelength.

The BRDF for each of the surfaces (except water) is computed from an invented analytic expression containing spectral and directional parameters which have been fitted to the (meager) available data, presented in Section 2. Also presented are derivations of directional-hemispherical reflectance from the BRDF and the directional emissivity.

For a water surface, Subroutine ESURF calls Subroutine GLITTR to obtain the BRDF and directional emissivity. Subroutine GLITTR, its auxiliary routines, and the underlying model for the glitter from a wind-ruffled water surface are described in Section 3. The model is based largely on the work of Cox and Munk [CM-54], including (1) the basic equation relating the glitter radiance to the wave-facet slope-probability distribution, (2) a two-dimensional isotropic normal distribution for the slope-probability distribution, and (3) a linear relation between the slope variance and the wind speed. Modifications and extensions of the Cox-Munk work include (1) using the Levanon-derived [Le-71b] equations for the slope and angle of incidence required at a viewed point to provide a glint, in terms of the position of an arbitrary-altitude detector viewing a spherical Earth, instead of the equations for a flat Earth as (appropriately) used by Cox and Munk, (2) evaluating the Fresnel equations for the specular reflectance in terms of the complex

index of refraction of water for the 2- to 5-μm region, instead of the visible region, (3) incorporating a shadowing factor (based on the work of Saunders [Sa-67, Sa-67a, Sa-68c] but extended to permit a "bistatic" dependence on the zenith angles of both the incoming and outgoing rays) which multiplies the slope probability distribution and takes account of shadowing of some slopes by others for illuminating and viewing near the horizon, and (4) providing a solution (by iteration) for the location of the specular reflectance point on a spherical-Earth water surface that is smooth for zero wind speed. The directional emissivity of the wind-ruffled water surface is approximated by that for a smooth water surface owing to the complex geometry which prevents analytically integrating the BRDF over a hemisphere.

In Section 4 we present the ROSCOE-IR model (23e) for the solar spectral irradiance at the top of the atmosphere, in the spectral range from 2 to 5 μm. The input data to the model, taken to be the NASA data adopted by the American Society of Testing and Materials, have been fitted by piecewise-continuous power-law expressions. The model may be called with either wavelength (μm) or wavenumber (cm^{-1}) and an index which selects the output spectral irradiance in any of four forms. Therein are presented derivations and a flow d gram of Subroutine SOLRAD.

In Section 5 we present the ROSCOE-IR model (23b) for the Earth surface radiance. The model provides two components of the radiance directed along the path $\overrightarrow{PV}$ in Figure 1-1: (1) thermal radiation emitted at Point P and (2) solar radiation reflected at Point P. Strictly, the surface-reflected solar radiation is actually provided in an unattenuated form with the path parameters required as part of the input to a later computation of the molecular absorption over the total two-leg path ($\overrightarrow{SP}$ + $\overrightarrow{PV}$). The aerosol transmittance along the incoming path $\overrightarrow{SP}$ is also provided. The principal routine in the model, Subroutine SURRAD, and its auxiliary geometry routine (Subroutine RINOUT) are described, including derivations of the zenith angle of the sun (θ_s), zenith angle of the detector (θ_d), and azimuth angle of the solar ray reflected toward the detector (ψ). We also provide detailed summaries of the inputs and outputs for the routines developed by other organizations (G.E. Tempo and Visidyne, Inc.) which we use to complete the model.

Subroutine SURRAD also provides for natural clouds if they are included in the calculation. While clouds are not strictly an Earth-surface feature, the treatment of the two components of the radiance along the path $\overrightarrow{CV}$ in Figure 1-1, resulting from cloud tops (the highest of which is 12 km in the Natural Cloud Model and shown as Point C in Figure 1-1), is analogous to that for Point P and thus is appropriately included.

The ROSCOE-IR model (23e) for the upwelling natural radiation is presented in Section 6. This model evaluates the mean upwelling spectral radiance at Point V (in Figure 1-1) by averaging the radiance over the solid angle (Ω_T) defined by the cone with vertex at Point V and tangent to the Earth's surface. In practice, we average the set of radiances received at Point V by viewing (in the absence of clouds) a set of characteristic Points P on the Earth's surface and within Ω_T. The Points P are selected in terms of a set of angles (β) measured from the nadir and a set of azimuth angles (ϕ) for each nadir angle. The results from the Earth Surface Radiance Model for each Point P are augmented by computing (1) the air emission along the path $\overrightarrow{PV}$, (2) the molecular path parameters along $\overrightarrow{PV}$, (3) the total path parameters along ($\overrightarrow{SP}$ + $\overrightarrow{PV}$) by adding those for $\overrightarrow{SP}$ and $\overrightarrow{PV}$, (4) the molecular transmittance for the path $\overrightarrow{PV}$ and for the total path ($\overrightarrow{SP}$ + $\overrightarrow{PV}$), and (5) the aerosol transmittance for the path $\overrightarrow{PV}$ and the total path ($\overrightarrow{SP}$ + $\overrightarrow{PV}$).

The inclusion of the statistical submodel of the Natural Cloud Model complicates the modeling. Now, for each Point C there is a distribution of radiance values corresponding to the 159 sets of three-layer cloud configurations. Details are given in Section 6.

The principal routine in the Upwelling Natural Radiation Model is Subroutine UPWELL; it is lengthly, with 20 pages of FORTRAN. In Section 6 we present formulas for the geometry involved, the radiance computed, a detailed summary of the calculational steps, and a detailed summary of the input and output variables.

In Section 6 we also provide detailed summaries of the input and output variables for all the auxiliary routines which are called by Subroutine

UPWELL but which are not so documented elsewhere. These routines include a number prepared by SAI and three important ones (Subroutines TRNSCO, ATMRAD, and TRANS) prepared by G.E. Tempo.

In Section 7 we provide general coding information for the NBR Module, including that required for the stand-alone version. We identify all of the (66 non-DSA) routines in the NBR Module and provide a chart showing their calling-structure relationships. For each of these routines we also state (1) the function it performs, (2) its originator, (3) the location of a listing of the routine, and (for 27 routines) (4) the number of the table in this volume which states in detail the inputs and outputs of the routine. For common blocks we provide (1) a matrix showing routines and the 35 common blocks appearing in them and (2) either definitions of all the variables in the common block and where the variables are set or a specific reference where the definitions are given.

The NBR Module in its stand-alone version is driven by Program DRVUPW (11 pages of FORTRAN). For this program we describe in Section 7 the calculational steps required in both the initialization and operation phases. During the initialization, calls are made to QINITL (for the DSA routines), ATMOSU (for the ambient atmosphere depending on time and location), CLOUDO (for cloud properties), TRANSB (for molecular band-model parameters for transmittance), and SHELLS (for atmospheric grid). During operation, calls are made to SETALT (to determine the altitudes (depending on wavelengths of interest) at which Subroutine UPWELL is to compute the upwelling natural background radiation) and UPWELL. Our development of Subroutine SETALT is described. Summaries of input and output variables are provided for Subroutine SETALT and the G.E. Tempo routines TRANSB and SHELLS.

Finally, in Section 7, we provide some comments on the integration of the NBR Module into ROSCOE-IR, including some of the differences between the stand-alone version and that in ROSCOE-IR. In particular, we summarize the inputs and outputs of Subroutine UPWELT, prepared by GRC, to select the appropriate wavenumber interval and to interpolate in altitude the upwelling natural radiation array.

In Section 8 we provide a listing of those (37) routines in the NBR Module which are not listed elsewhere (at least not as we are using them). These include 19 SAI routines, 17 G.E. Tempo routines, and 1 Visidyne, Inc. routine.

SECTION 2

EARTH SURFACE CHARACTERIZATION: GENERAL AND NON-WATER SURFACES

2-1 INTRODUCTION AND SUMMARY

2-1.1 Requirements for the Model

The characterization of the Earth's surface is required for input to the Earth Surface Radiance Model (23b) and the Upwelling Natural Radiation Model (23c) via Model 23b. For the Earth Surface Radiance Model, Model 23a is required to provide the reflectance, emittance, and temperature of the Earth's surface at the point (P) where the optical line-of-sight intersects the Earth's surface, including directional effects as necessary. For the Upwelling Natural Radiation Model, Model 23a is required to provide the average characteristics (i.e., reflectance, emittance, and temperature) of that portion of the Earth's surface that could be viewed from an altitude of interest.

2-1.2 Approach

The reflectance and emittance properties of the Earth's surface are controlled mainly by composition and to a lesser extent by surface roughness. Since the composition and roughness of the Earth's surface can vary markedly from point to point, so can its optical properties. A useful summary of the reflectance data for the Earth's surface features was prepared by Bartman in his thesis [Ba-67b]; this summary has been reproduced by Kondratyev [Ko-72d] and is shown here as Table 2-1. This table is of general interest for us even though Bartman and Kondratyev were mainly interested in the Earth's total albedo for solar radiation and hence emphasized the visible spectral region.

It has been agreed to represent the Earth's surface in a relatively simple way, yet one which provides a range of reflectance, emittance, and temperature values. The general procedure is to provide for six categories of the Earth's surface: water, snow, sand, soil, foliage, and urban material.

Table 2-1. Summary of reflectance data for the Earth's surface features. (Reproduced from Ko-72d; originally prepared by Bartman [Ba-67b].)

Surface	*Spectral characteristics*	*Angular distribution of reflectance*	*Total reflectance*
Soils and rocks	1. Increasing to 1 micron 2. Decreasing above 2 microns 3. Moisture decreases reflectance	1. Backscattering and forward scattering 2. Sand has large forward scattering 3. Loam has small forward scattering	1. 5–45% 2. Moisture decreases reflectance by 5–20% 3. Smooth surfaces have higher reflectance 4. Diurnal variation, maximum reflectance for small sun angles
Vegetation	1. Small (below 0.5 micron) 2. A small maximum bump at 0.5 to 0.55 micron 3. Chlorophyll absorption at 0.68 micron 4. Sharp increase at 0.7 micron 5. Decrease above 2 microns 6. Depends on growing season	1. Backscattering 2. Small forward scattering	1. 5–25% 2. Diurnal effects, maximum reflectance for small angles 3. Marked annual variation
Water basins	1. Maximum at 0.5–0.7 micron 2. Depends on turbidity and waves	1. Large back and forward scattering	1. Small reflectance 2. Diurnal variation maximum for small sun angles 3. Depends on turbidity and waves
Snow and ice	1. Decreases slightly with increasing wave-length 2. Large variability depending on purity, wetness, physical condition	1. Diffuse component plus mirror component 2. Mirror component increases with increasing angle of incidence	1. Variable, 25–80% 2. 84%, in Antarctic 3. 74%, Ross Sea ice 4. 30–40%, White Sea ice

For each category the reflectance and emittance have been chosen to be representative of the average value for that category. The chosen values are based on those we have been able to find in the literature so far; one should remain alert to possibly finding improved values. There is no automatic correlation between geographic position and surface category. However, the user could, in principle, place different surfaces as he desires in a given scene when he wants to address surface boundary problems, but the necessary coding has not been implemented. For test and possibly other purposes, we also provide for a Lambertian surface with a user-defined value of the diffuse reflectance.

A review of the literature has convinced the writer that most materials have a strong non-diffuse character. To take account of the non-diffuseness, we postulate a general expression for the bidirectional reflectance-

distribution function (frequently referred to as BRDF) with several parameters that are evaluated on the basis of whatever experiemental data are available. (The reader unfamiliar with the quantity we call the BRDF - which has many aliases, including partial reflectance or reflectance-distribution function - may want to refer to the discussions by Wolfe [Wo-65a, pp. 23-28] or by Nicodemus [Ni-65c, Ni-70d, Ni-76].)

Having determined the BRDF for a material, one can then integrate the BRDF over a hemisphere to obtain the directional-hemispherical reflectance (which is equal to the hemispherical-directional reflectance) and thus obtain the directional emissivity for the material by applying Kirchhoff's law [Ni-70d].

2-1.3 The Bidirectional Reflectance-Distribution Function (BRDF)

We follow the recommendation of Nicodemus [Ni-70d] and use the symbol f_r to represent the BRDF, which has the units of sr^{-1}. The general form we propose for the BRDF is

$$
\begin{aligned}
f_r &\equiv f_r[m, D(m), \lambda; \theta_i, \theta_r, \psi], \quad m \geq 2 \\
&= \rho_{om}(\lambda)\,\{1 + R_m(\psi)\exp(-\alpha_m[(\cos\theta_i)^{\gamma_m} + (\cos\theta_r)^{\gamma_m} \\
&\qquad + \beta_m(1-|1-2\psi/\pi|)])\}, \quad sr^{-1}
\end{aligned}
\tag{1}
$$

where

$$
R_m(\psi) = R_m(0) - [R_m(0) - R_m(\pi)]\psi/\pi \, . \tag{2}
$$

For the Lambertian surface (m=1), the BRDF is a constant, given by

$$
f_r = \rho_{o1}(\lambda) \tag{1'}
$$

with

$$R_1(0) = R_1(\pi) = 0 \ . \tag{2'}$$

In Equation (1), the symbols have the following meanings.

- m - Index for category of surface material.
- $D(m)$ - Additional descriptor available for the mth material, if needed. For brevity, we will frequently suppress $D(m)$ as an explicit argument.
- λ - Wavelength (μm).
- θ_i - Zenith angle of sun at intersection point (P).
- θ_r - Zenith angle of detector at intersection point (P).
- ψ - Azimuth angle (at intersection point (P)) of vertical plane through line-of-sight, measured relative to the solar principal plane (i.e., vertical plane through the source ray). Values of zero and π for ψ correspond to forward and backward scattering, respectively.

There are six parameters - $\rho_{om}(\lambda)$, $R_m(0)$, $R_m(\pi)$, a_m, β_m, and γ_m - characterizing a material, according to our Equation (1). Note that all of the spectral dependence of the reflectance is contained in the parameter $\rho_{om}(\lambda)$, which has no directional dependence; i.e., we assume that the spectral and directional properties are separable. The parameters $R_m(0)$ and $R_m(\pi)$, together with a_m and γ_m, control the forward and backward reflection in the principal plane; the parameter β_m controls the scattering away from the principal plane.

In addition to the separability of the spectral and directional properties, our expression for the BRDF has two other important properties. The more important of these is that Equation (1) satisfies the Helmholtz reciprocity theorem [Ni-65c] according to which f_r must be invariant to an interchange of the incident and reflected rays. The third principal property of Equation (1) is that f_r is integrable over a hemisphere provided γ_m equals 1 or 2. Whereas we have imposed this restriction in the determination of the other

parameters, we recognize in retrospect that this requirement could probably be relaxed for practical applications in which the quality of the fits to experimental data might be improved if γ_m had other values. We do not claim uniqueness for Equation (1), but it is the only expression of its kind of which we are aware. Further thought - with more trials and errors - may lead to a better expression.

Finally, we mention an odd property of our BRDF which is not of much practical consequence but which may be a small wonderment. This property is that, for $\theta_i = \theta_r = 0$ (i.e., normal incidence and reflection), f_r as given by Equation (1) is multivalued in that it depends on the value of ψ. Of course, physically we expect a single value. Our practical solution to this problem, for $\theta_i = \theta_r = 0$, is simply to define f_r to be the value obtained by averaging $f_r(0,0,\psi)$ over ψ, i.e.,

$$f_r\big|_{\theta_i = \theta_r = 0} \equiv \langle f_r(0,0,\psi)\rangle \ . \tag{3}$$

From the integrations presented in Section 2-4 we show that

$$\boxed{\langle f_r(0,0,\psi)\rangle = \rho_{om}\,[1+e^{-2\alpha_m}\,\bar{R}_m\,P_1(\alpha_m\beta_m)]} \tag{3a}$$

where

$$\bar{R}_m = [R_m(0) + R_m(\pi)]/2 \tag{4a}$$

$$P_1(a) = \int_0^1 dx e^{-ax} = \frac{1}{a}\,(1-e^{-a}) \ . \tag{4b}$$

2-1.4 The Directional-Hemispherical Reflectance

The spectral, directional-hemispherical reflectance, denoted here by $\rho_m(\lambda;\theta_i,2\pi)$, is defined [Ni-65c, Wo-65a] by the integral

$$\rho_m(\lambda;\theta_i,2\pi) = \int f_r \cos\theta_r \, d\Omega_r \tag{5}$$

where

$$d\Omega_r = \sin\theta_r \, d\psi_r \, d\theta_r \; . \tag{5a}$$

In Section 2-4 we show that the result of the integration, when Equation (1) is used for f_r, is

$$\boxed{\rho_m(\lambda;\theta_i,2\pi) = \pi\rho_{om}(\lambda)\; G(\alpha_m,\beta_m,\gamma_m;\theta_i), \quad m \geq 2} \tag{6}$$

with

$$G(\alpha_m,\beta_m,\gamma_m;\theta_i) = 1 + 2\; P_1(\alpha_m\beta_m)\; P_{2\gamma_m}(\alpha_m) R_m F_{\gamma_m}(\alpha_m,\theta_i) \tag{7}$$

$$P_{21}(a) = \int_0^1 dx x e^{-ax} = \frac{1}{a^2}\,[1 - e^{-a}(a+1)] \tag{8}$$

$$P_{22}(a) = \int_0^1 dx x e^{-ax^2} = \frac{1}{2a}\,(1 - e^{-a}) \tag{9}$$

$$F_{\gamma_m}(a,\theta) = \exp[-a(\cos\theta)^{\gamma_m}]. \tag{10}$$

For a Lambertian surface (m=1),

$$\rho_1(\lambda;\theta_i,2\pi) = \pi\rho_{01}(\lambda) \; . \tag{6'}$$

If the spectral directional-hemispherical reflectance, $\rho_m(\lambda;\theta_i,2\pi)$, for a material is known from experiment for at least one value of θ_i and if the five directional parameters α_m, β_m, γ_m, $R_m(0)$, and $R_m(\pi)$ are known, then

our spectral parameter $\rho_{om}(\lambda)$ in Equation (1) can be determined from Equation (6) evaluated at the given θ_i. In practice, the directional-hemispherical reflectance is frequently measured for a direction at or near normal incidence. In this case, for at least the materials we have examined, the quantity $G(\alpha_m,\beta_m,\gamma_m;\theta_i=0)$ - which is a measure of the departure of the BRDF from a constant, as it would be for a diffuse reflector - differs from unity by only a few percent (9.5% in one case). Thus, in practice, it would be a good approximation to simply evaluate $\rho_{om}(\lambda)$ by the relation

$$\rho_{om}(\lambda) \approx \pi^{-1} \rho_m(\lambda;\theta_i=0,2\pi) \; ; \tag{11}$$

however, for self-consistency, to get $\rho_{om}(\lambda)$ we have used Equation (6) evaluated at $\theta_i=0$ with $\rho_m(\lambda;\theta_i=0,2\pi)$ given by (meager) experimental data, i.e., we have used

$$\boxed{\rho_{om}(\lambda) = \frac{\rho_m(\lambda;\theta_i=0,2\pi)}{\pi G(\alpha_m,\beta_m,\gamma_m;\theta_i=0)} \; , \; m \geq 2} \tag{6''}$$

2-1.5 The Directional Emissivity

The directional emissivity, ϵ_d, for material m, at a zenith angle θ, is [Ni-65c, Ni-70d]

$$\boxed{\epsilon_d \equiv \epsilon_d(m,\lambda,\theta) = 1-\rho_m(\lambda;\theta,2\pi)} \tag{12}$$

where the directional-hemispherical reflectance $\rho_m(\lambda;\theta,2\pi)$ is given by Equation (5) in general and by Equation (6) when our f_r (Equation (1)) is used in Equation (5). For a Lambertian surface (m=1),

$$\epsilon_d(1,\lambda,\theta) = 1-\rho_1(\lambda;\theta,2\pi) = 1-\pi\rho_{o1}(\lambda) \; . \tag{12'}$$

For urban material (m=7), see Section 2-3.5.2 for the special form appropriate for urban geometry.

2-1.6 Summary of Parameters for the BRDF

A perusal of the literature, including the putative extensive NASA data base [LE-71a, LE-72c], has so far revealed very few photometric data of the type desired, i.e., bidirectional spectral reflectance data in the 2- to 5-μm region. The data available typically are broad-band and usually include the visible region. Bidirectionality is usually lost in that the data are usually for hemispherical-directional or hemispherical-hemispherical conditions. Where there are spectral data of interest, the directional data are lacking; similarly, where there are directional data, the spectral region or resolution is wrong. Where the data are taken under field conditions, not only the sun but the sky radiance is mixed in.

Despite these difficulties, however, we have boldly arrived at the values for the parameters, recorded in Tables 2-2a and 2-3. The details of the derivation of these parameters are given in Sections 2-2 and 2-3.

In Table 2-2b, we present the azimuthal dependence of f_r for $\theta_i = \theta_r = 0$, as well as $\langle f_r(0,0,\psi)\rangle$.

2-1.7 Surface Temperature

The remaining required specification, surface temperature, may be chosen to be equal to the ambient air temperature at the Earth's surface. This assumption is reasonably correct for all cases at night, and for water, snow, and foliaged surfaces during the day. This assumption leads to significantly low surface temperatures for other surfaces (barren soil, sand, and urban materials) during periods of solar illumination. However, because of the complexity of modeling this phenomenon, and the fact that the natural Earth surface radiance is only a baseline for nuclear effects, use of the ambient air temperature as the surface temperature is currently recommended; however, consideration should be given later (if resources permit) to developing a better prescription for the surface temperature.

Table 2-2a. Spectral and directional parameters for characterization of the BRDF for Earth surface materials.*

Material	m	D(m)	Spectral $P_{om}(\lambda)$	Directional α_m	β_m	γ_m	$R_m(0)$	$R_m(\pi)$	$\bar{R}_m$
Lambertian	1	a	$D(1)/\pi$	-	-	-	0	0	0
Water	2	b	f	-	-	-	-	-	-
Snow	3	c	g	3	0.9	1	13	3	8
Sand	4	d	h	3	0.5	1	2.5	4	3.25
Soil	5	d	i	2.5	0.5	2	1	4	2.5
Vegetation	6	d	j	2.5	0.5	2	1	10	5.5
Urban Materials	7	e	k	4	0.5	2	10.5	1	5.75

Material	m	Directional (continued) $P_1(\alpha_m\beta_m)$	$P_{2\gamma_m}(\alpha_m)$	$F_{\gamma_m}(\alpha_m,0)$	$\omega(\alpha_m,\beta_m,\gamma_m;0)$
Lambertian	1	-	-	-	1.00
Water	2	-	-	-	-
Snow	3	.345	.0890	.0498	1.024
Sand	4	.518	.0890	.0498	1.015
Soil	5	.571	.184	.0821	1.043
Vegetation	6	.571	.184	.0821	1.095
Urban Materials	7	.432	.123	.0183	1.011

*Footnotes are on the following page.

Footnotes for Table 2-2a.

---

[a] D(1) is the diffuse reflectance ($\rho_1 = \pi\rho_{01}$) for a Lambertian surface. A typical value is 0.1.

[b] D(2) is the wind speed, $0 \le D(2)$, m/sec.

[c] D(3) is the snow-age parameter, $0 \le D(3) \le 1$. Values of zero and one correspond to new and old snow, respectively.

[d] Not used.

[e] D(7) is the degree-of-urbanization factor, $0 \le D(7) \le 1$. A value of zero for D(7) provides a spectral-dependent BRDF corresponding to a flat surface with directional reflectance properties equal to the average for concrete and asphalt. A value of one for D(7) provides a spectral-dependent BRDF corresponding to a diffuse reflector but modified by a shadow factor $S(\theta_i,\theta_r) = (\cos\theta_i + \cos\theta_r)/2$.

[f] See Section 3 for treatment of water.

[g] Evaluated from Equation (6'') with ρ_3 given in Table 2-3 by a formula with dependence on the snow-age parameter, D(3).

[h] Evaluated from Equation (6'') with ρ_4, given in Table 2-3, being the average value for natural gypsum sand [Ho-66, Figure 10] and Russian sand [Kropotkin (1964) per Ba-67b, Figure 82].

[i] Evaluated from Equation (6'') with ρ_5, given in Table 2-3, being the average value for topsoil [RH-73, p. 15-20], Pawnee Grassland soil [Ho-66, Figure 9], and Russian soil [Kropotkin (1964) per Ba-67b, Figure 82].

[j] Evaluated from Equation (6'') with ρ_6, given in Table 2-3, based on data provided by D.C. Anding, said to be an average of many values in LE-71a for $2.0 \le (\mu m) \le 2.5$ and estimated for $2.5 < \lambda(\mu m) \le 5$.

[k] Evaluated from Equation (6'') with ρ_7, given in Table 2-3, being the average value for Russian asphalt, asphaltic material [Wo-65a, Figure 4-23], Russian (red) brick, and Russian concrete. Russian data are given by Kropotkin (1964) per Ba-67b, Figure 82.

Table 2-2b. $\langle f_r(0,0,\psi)\rangle$ and azimuthal dependence of $f_r(0,0,\psi)$.

m	$\rho_0^{-1} f_r(0,0,0)$	$\rho_0^{-1} f_r(0,0,\pi/2)$	$\rho_0^{-1} f_r(0,0,\pi)$	$\rho_0^{-1} \langle f_r(0,0,\psi)\rangle$
3	1.032	1.0013	1.0074	1.0068
4	1.0062	1.0018	1.0099	1.0042
5	1.0067	1.0048	1.027	1.0096
6	1.0067	1.011	1.067	1.021
7	1.0035	1.00026	1.00034	1.00083

Table 2-3. Normal-incidence--hemispherical reflectance for Earth surface materials.[a]

Snow

$$\rho_3 = [0.44 - 0.12\ (\lambda-2)]\ [1-(5/12)\ D(3)]$$

Soil

λ, μm	ρ_5	λ, μm	ρ_5
2.00	0.262	3.15	0.067
2.08	.272	3.50	.112
2.25	.257	3.70	.158
2.50	.227	3.82	.177
2.62	.198	4.10	.195
2.70	.095	4.60	.158
2.77	.067	4.77	.142
2.92	0.061	5.00	0.113

Sand

λ, μm	ρ_4	λ, μm	ρ_4
2.00	0.205	2.95	0.040
2.05	.238	3.20	.070
2.18	.209	3.30	.093
2.30	.206	3.60	.145
2.45	.177	3.75	.162
2.50	.174	3.90	.152
2.63	.148	4.35	.076
2.73	.114	4.90	.031
2.88	0.080	5.00	0.035

Vegetation

λ, μm	ρ_6	λ, μm	ρ_6
2.00	0.129	3.16	0.033
2.20	.212	3.22	.033
2.64	.059	3.42	.074
2.78	.059	3.58	.074
2.96	.120	3.95	.037
3.03	0.120	5.00	0.021

(continued)

Table 2-3. Normal-incidence--hemispherical reflectance for Earth surface materials[a] (Cont'd).

Urban Materials					
λ, µm	ρ_7	λ, µm	ρ_7	λ, µm	ρ_7
2.00	0.347	2.70	0.272	4.00	0.231
2.12	.348	2.85	.145	4.10	.238
2.24	.326	2.89	.118	4.26	.240
2.26	.278	3.00	.090	4.42	.254
2.36	.272	3.10	.091	4.70	.246
2.47	.295	3.24	.100	4.83	.229
2.55	.299	3.62	.149	5.00	0.215
2.63	0.296	3.89	0.193		

[a]In this table, for brevity, we use the notation $\rho_m \equiv \rho_m(\lambda,0,2\pi)$ for the spectral, normal-incidence--hemispherical reflectance.

2-2 EVALUATION OF SPECTRAL DATA FOR THE BRDF

2-2.1 Snow

For snow, we have found very limited spectral reflectance data in the 2- to 5-µm region, although there are considerable spectral data in the visible region [Ko-73a, pp. 227-229, 231] and albedo data [Ko-72d]. Kondratyev [Ko-73a, p.234, Figure 4.12] reports spectral reflectance data for old snow for $\lambda \leq 2.5$ µm and for fresh snow for $\lambda \leq 2.2$ µm; these values are much smaller than those we have adopted, taken from graphs given by Rose et al. [RA-73, Figures 37b, 37c] (or WZ-78, Figure 3-19) and attributed to Russian literature which we have not yet acquired for verification. The data from RA-73, which are limited to $\lambda \leq 4.0$ µm, are replotted in Figure 2-1 where they are extrapolated to 5 µm. By using the slopes of the curves in the 3- to 4-µm region, we have very well fitted the two curves by the single equation

$$\rho_3 = [0.44 - 0.12\ (\lambda - 2)]\ [1-(5/12)\ \delta(3)] \qquad (13)$$

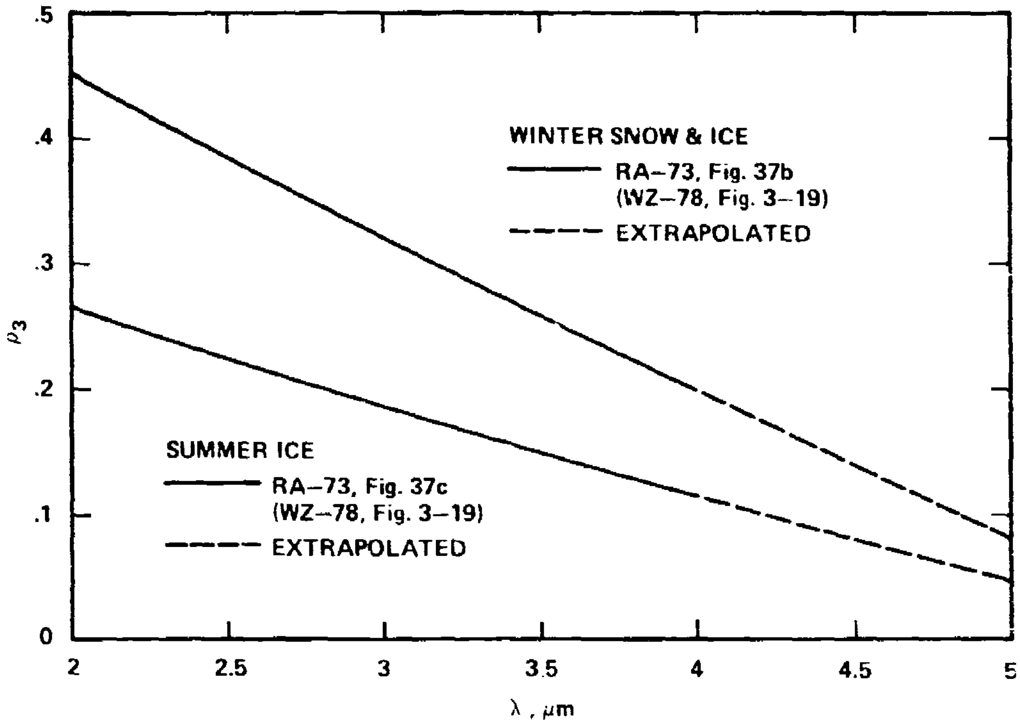


Figure 2–1. Spectral diffuse reflectance of winter snow and ice and summer ice (2 to 5 μm).

in which we have introduced the snow-age parameter D(3) to which we assign the value of zero for winter snow and ice and the value of unity for summer ice. Intermediate curves can be interpolated by using intermediate values of D(3), $0 \leq D(3) \leq 1.0$.

2-2.2 Sand

Hemispherical--normal-directional spectral reflectance data in the range $0.5<\lambda(\mu m) \leq 6$ are given by Hovis [Ho-66] for pure silica sand, beach sands (from New Jersey and Florida) which are largely silica, and gypsum sand, common in much of the soil of the western United States, particularly in the sand of the White Sands National Monument in New Mexico. For gypsum sand, Hovis [Ho-66] shows reflectance data for samples of both its natural state and

partially dehydrated state. Spectral data for (Russian) sand, not otherwise identified, are given by Kropotkin [(1964), per Ba-67b, Figure 82]. The data from Kropotkin are reproduced as Figure 2-2. The results of digitizing the Hovis curve [Ho-66, Figure 10] for the natural-state gypsum sand and those for the Russian sand are given in Table 2-4; these data are plotted in Figure 2-3. The results of averaging the digitized data for the natural gypsum sand and the Russian sand are given in Table 2-3 and plotted as the dashed curve in Figure 2-3.

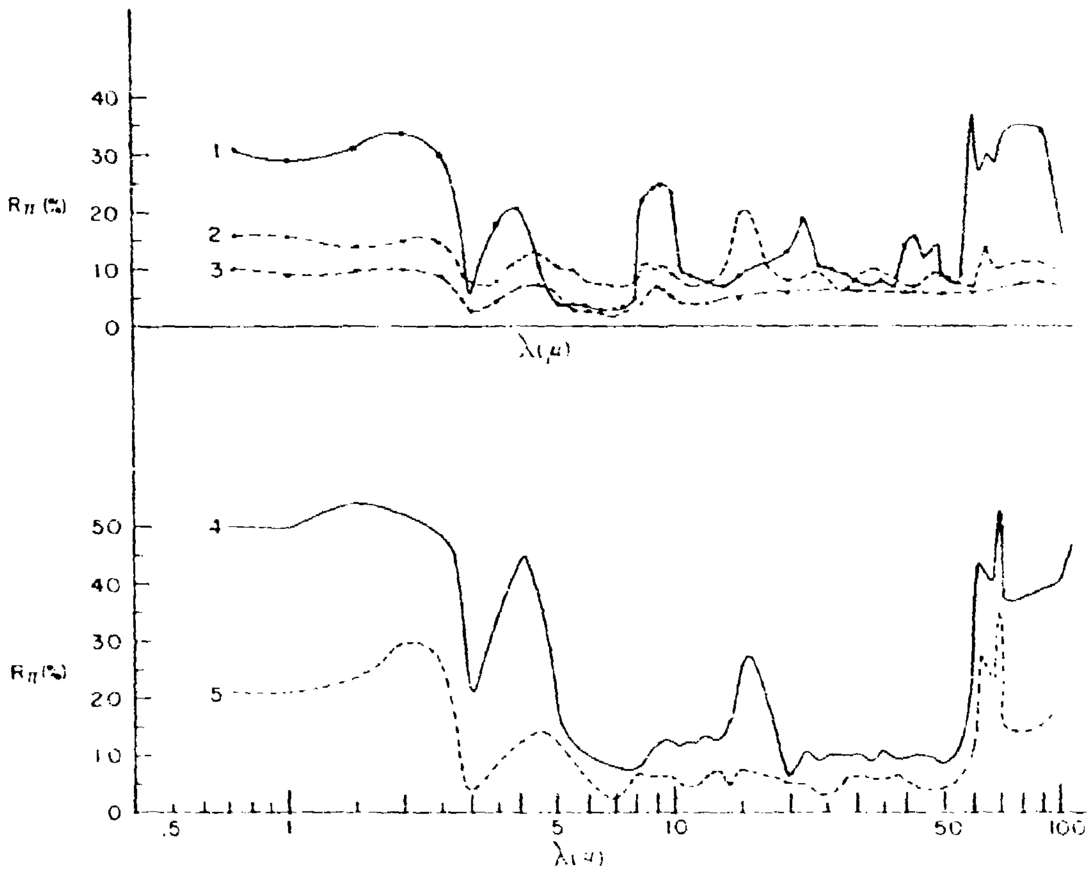


Figure 2–2. Spectral reflectance for (1) sand, (2) soil, (3) asphalt, (4) brick, and (5) concrete (after Kropotkin et al., per Ba–67b, Figure 82).

Table 2-4. Spectral reflectance of sand, ρ_4.

Natural Gypsum Sand [a]		Russian Sand [b]	
λ, µm	ρ_4	λ, µm	ρ_4
2.00	0.07	2.00	0.34
2.05	.14	2.25	.325
2.18	.09	2.50	.30
2.30	.095	2.65	.25
2.45	.05	2.78	.20
2.63	.04	2.88	.15
2.73	.01	2.95	.06
2.87	.01	3.10	.10
2.95	.02	3.30	.15
3.20	.015	3.60	.20
3.75	.12	3.90	.21
4.35	.015	4.00	.20
4.80	.015	4.90	.04
5.00	0.03	5.00	0.04

[a] Hovis [Ho-66, Figure 10].

[b] Kropotkin (1964) [Ba-67b, Figure 82].

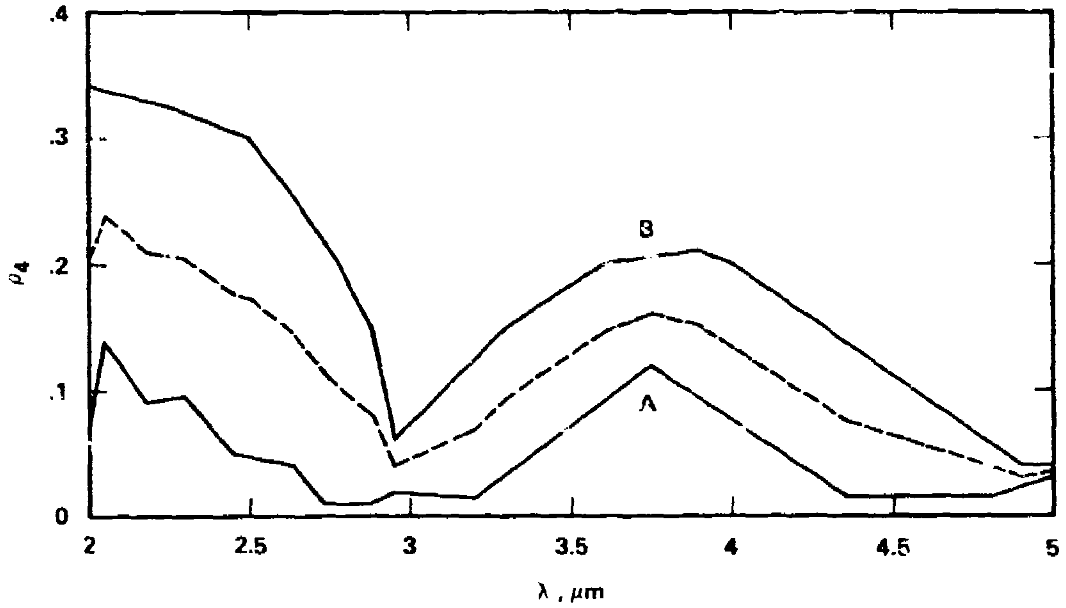


Figure 2–3. Spectral reflectance for sand, ρ_4. Dashed curve is average of (A) natural gypsum sand [Hovis, Ho–66, Figure 10] and (B) Russian sand (Kropotkin (1964) per Bartman [Ba–67b, Figure 82]).

2-2.3 Soil

Hovis [Ho-66, Figure 9] presents the hemispherical--normal-directional reflectance of soil from the Pawnee Grassland area in Colorado. The results of digitizing the Hovis curve are given in Table 2-5 and plotted in Figure 2-4.

RH-73 (p. 15-20, Figure 10) presents the normal emittance of topsoil. The results of digitizing this curve and computing the normal reflectance are given in Table 2-5 and plotted in Figure 2-4.

Spectral data for (Russian) soil, not otherwise identified, are given by Kropotkin [(1964) per Ba-67b, Figure 82], reproduced here as Figure 2-2. The results of digitizing the Kropotkin curve are given in Table 2-5 and plotted in Figure 2 4.

The results of averaging the digitized data for the Pawnee Grassland soil [Ho-66], the topsoil reported in RH-73, and the Russian soil [Ba-67b] are given in Table 2-3 and plotted in Figure 2-4.

2-2.4 Vegetation

The following spectral reflectance data for vegetation were provided by D.C. Anding who says:

> "Values of spectral diffuse reflectance of vegetation representing the averages for many types of vegetation were obtained. The data were taken from LE-71a for $\lambda \leq 2.5$ μm for which the typical measurement procedure was to illuminate at normal incidence and collect hemispherical output. Values beyond 2.5 μm were estimated."

Table 2-5. Spectral reflectance of soil, ρ_5.

Pawnee Grassland Soil[a]

λ, μm	ρ_5
2.00	0.36
2.08	.395
2.62	.27
2.70	.045
3.15	.045
3.70	.22
4.10	.25
5.00	0.09

[a]Hovis [Ho-66, Fig. 9]

Topsoil[b]

λ, μm	$\epsilon_\perp$	$1-\epsilon_\perp=\rho_5$
2.00	0.725	0.275
2.50	.766	.234
2.61	.800	.200
2.77	.950	.050
2.92	.950	.050
3.15	.920	.080
3.50	.910	.090
3.82	.810	.190
4.15	.790	.210
4.77	.825	.175
5.00	0.860	0.140

[b]RH-73, p. 15-20, Fig. 10.

Russian Soil[c]

λ, μm	ρ_5
2.00	0.150
2.25	.160
2.50	.150
2.70	.125
2.85	.090
3.25	.075
4.10	.130
4.60	.130
5.00	0.110

[c]Kropotkin (1964) [Ba-67b, Fig. 32]

For $\lambda \leq 2.5$ μm, the data are the same as those given in Figure 37e of RA-73 (or Figure 3-19 of WZ-78); at longer wavelengths the curve in Figure 37e of RA-73 differs somewhat from the estimated data provided by Anding. The results of digitizing Anding's curve are given in Table 2-3 and plotted in Figure 2-5. Whereas we will use the curve in Figure 2-5, one should be alert for more specific data.

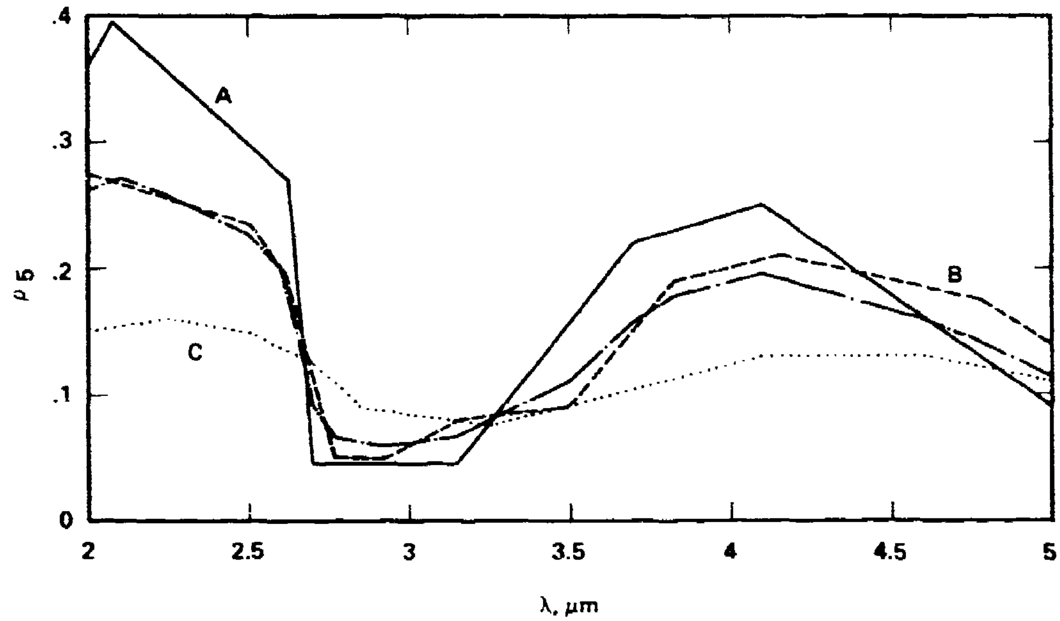


Figure 2–4. Spectral reflectance for soil, ρ_5. Dash–dot curve is average of (A) Pawnee Grassland soil [Ho–66, Figure 9], (B) Topsoil [RH–73, p. 15–20, Figure 10], and (C) Russian soil [Kropotkin (1964) per Ba–67b, Figure 82].

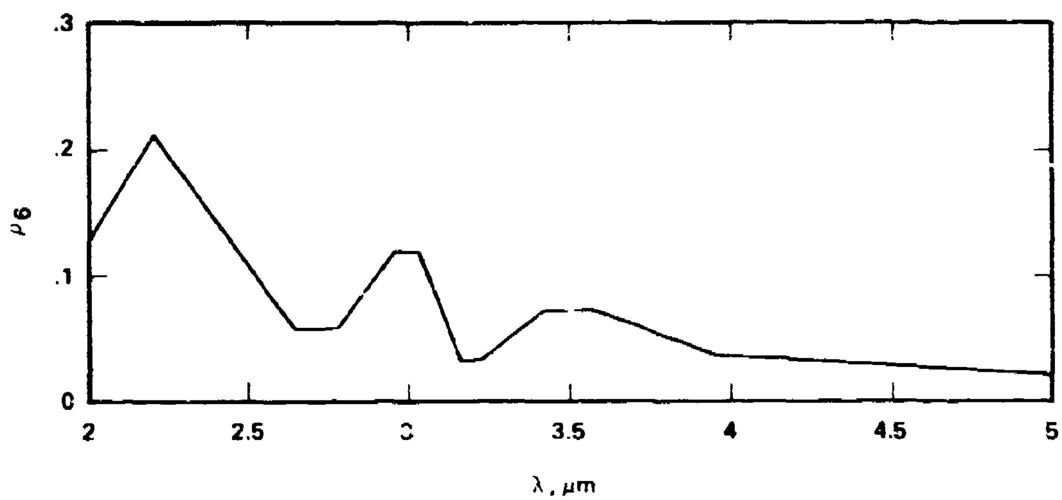


Figure 2–5. Spectral reflectance for vegetation, ρ_6.

2-2.5 Urban Materials

Wolfe [Wo-65a, Figure 4-23] reports the spectral reflectance of asphaltic road material. The results of digitizing this curve are given in Table 2-6 and plotted in Figure 2-6.

Spectral reflectance data for (Russian) asphalt, brick, and concrete are given by Kropotkin [(1964) per Ba-67b, Figure 67b], reproduced here as Figure 2-2. The result of digitizing these curves are given in Table 2-6 and plotted in Figure 2-6.

The results of averaging the digitized data for the asphaltic road material [Wo-65a] and the Russian asphalt, brick, and concrete are given in Table 2-3 and plotted in Figure 2-6.

2-3 EVALUATION OF DIRECTIONAL DATA FOR THE BRDF

2-3.1 Snow

Salomonson and Marlatt [SM-68, SM-68a] have measured spectrally integrated values (0.55 to 0.85 μm and 0.2 to 4.0 μm) of the BRDF's for clouds, snow and white gypsum sand. The ordinate in their Cartesian plots is actually π times the BRDF. The relative values of the ordinates on the curves for the 0.2- to 4.0-μm spectral interval have been digitized and they are given in Table 2-7.

The expression we have evaluated as the relative BRDF for snow is the ratio given by Equation (14),

$$F_r(\theta_i;\theta_r,\psi) \equiv \frac{f_r(\theta_i,\theta_r,\psi)}{f_r(\theta_i,\theta_r=0,\psi)} , \tag{14}$$

where $f_r(\theta_i,\theta_r,\psi)$ is given by Equation (1), with the five directional parameters (α_3, β_3, α_3, $R_3(0)$, and $R_3(\pi)$) as given in Table 2-2a for m=3. We have

Table 2-6. Spectral reflectance of some urban materials, ρ_7.

Asphaltic Road Material[a]

λ, µm	ρ_7
2.00	0.462
2.12	.480
2.24	.411
2.26	.226
2.36	.226
2.47	.346
2.63	.436
2.70	.436
2.89	.100
3.00	.074
3.15	.077
3.24	.042
3.38	.042
3.62	.068
3.89	.160
4.00	.279
4.26	.331
4.42	.419
4.62	.439
4.70	.467
4.83	.457
5.00	0.476

Asphalt[b]

λ, µm	ρ_7
2.00	0.100
2.50	.090
3.00	.025
4.00	.075
4.60	.075
5.00	0.060

Brick[b]

λ, µm	ρ_7
2.00	0.525
2.30	.500
2.50	.480
2.65	.465
3.00	.220
3.10	.220
3.50	.350
4.00	.450
4.10	.450
4.60	.350
5.00	0.200

Concrete[b]

λ, µm	ρ_7	λ, µm	ρ_7	λ, µm	ρ_7
2.00	0.300	2.65	0.200	4.30	0.140
2.20	.300	2.85	.040	4.60	.140
2.40	.275	3.10	.040	5.00	0.125
2.55	0.250	3.60	0.100		

[a]Wolfe [Wo-65a, Figure 4-23, p. 83]
[b]Kropotkin [(1964), Ba-67b, Figure 82]

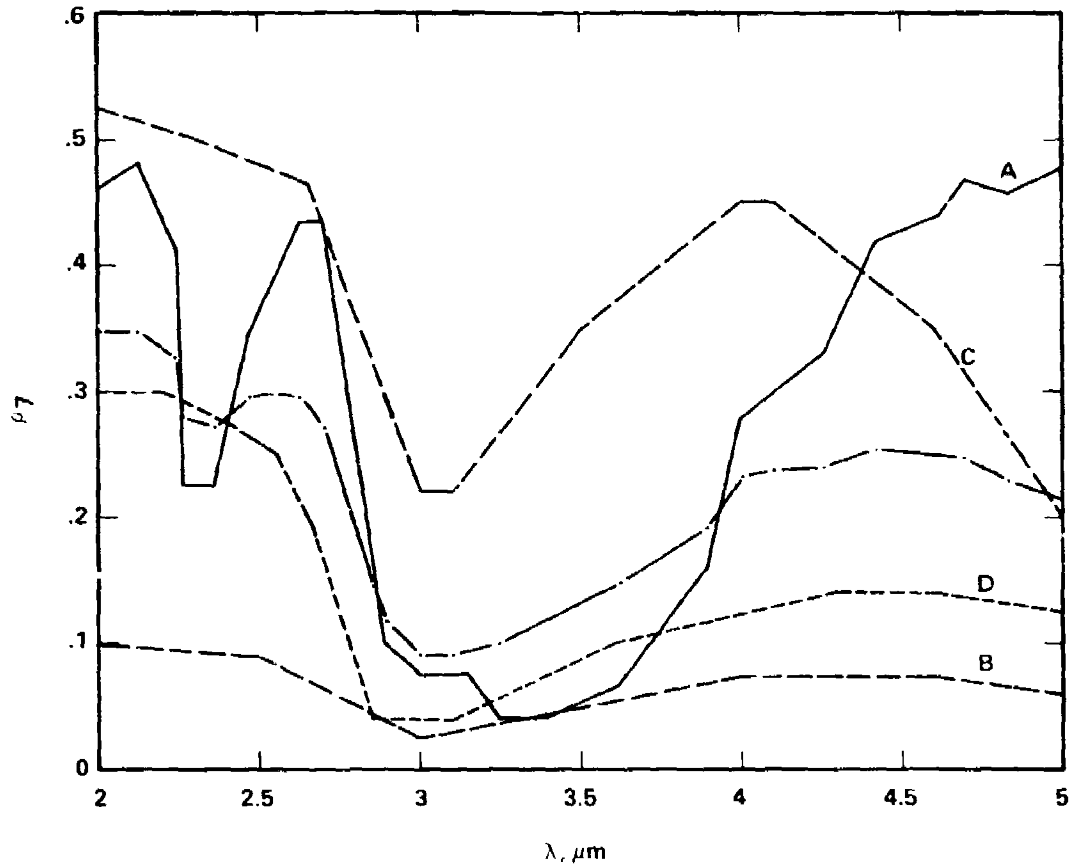


Figure 2–6. Spectral reflectance for urban materials, ρ_7. Dash–dot curve is average of (A) Asphaltic road material [Wo–65a, Figure 4–23, p. 83], (B) Asphalt [Kropotkin (1964) per Ba–67b, Figure 82], (C) Brick [Kropotkin (1964) per Ba–67b, Figure 82], and (D) Concrete [Kropotkin (1964) per Ba–67b, Figure 82].

plotted the results for the forward (ψ=0) and backward (ψ=π) directions as the set of continuous curves in Figure 2-7, with the lowest, middle, and highest portions corresponding to solar zenith angles (θ_i) of 64, 68, and 84 deg. The experimental values of SM-68 are also shown in Figure 2-7 for comparison.

Table 2.7. Relative directional reflectance of snow for solar zenith angles of θ_i = 64, 68, 84 deg, in the spectral range of 0.2 to 4.0 μm.[a]

Solar Zenith θ_i	Azimuth Angle ψ	Zenith Angle of Reflected Ray, θ_r: 0	45	60	75
64	0	1.00	1.26	1.52	1.97
	180		1.03	1.12	1.19
68	0		1.21	1.48	2.36
	180		1.21	1.31	1.48
84	0		1.63	2.26	4.11
	180		1.01	1.34	1.94

[a]Values inferred from Figures 16, 8, and 15 of Salomonson and Marlatt [SM-68].

2-3.2 Sand

Salomonson and Marlatt [SM-68] have also obtained results for white gypsum sand. The relative values of the ordinates on their curves for the 0.2- to 4.0-μm spectral interval have been digitized; they are given in Table 2-8.

The expression we have evaluated as the relative BRDF for sand is the ratio given by Equation (14) with the five directional parameters as given in Table 2-2a for m=4. We have plotted the results for the forward (ψ=0) and backward (ψ=π) directions as the set of continuous curves in Figure 2-8, with the lowest, middle, and highest portions corresponding to solar zenith angles (θ_i) of 21, 48, and 59 deg. The experimental values of SM-68 are also shown in Figure 2-8 for comparison.

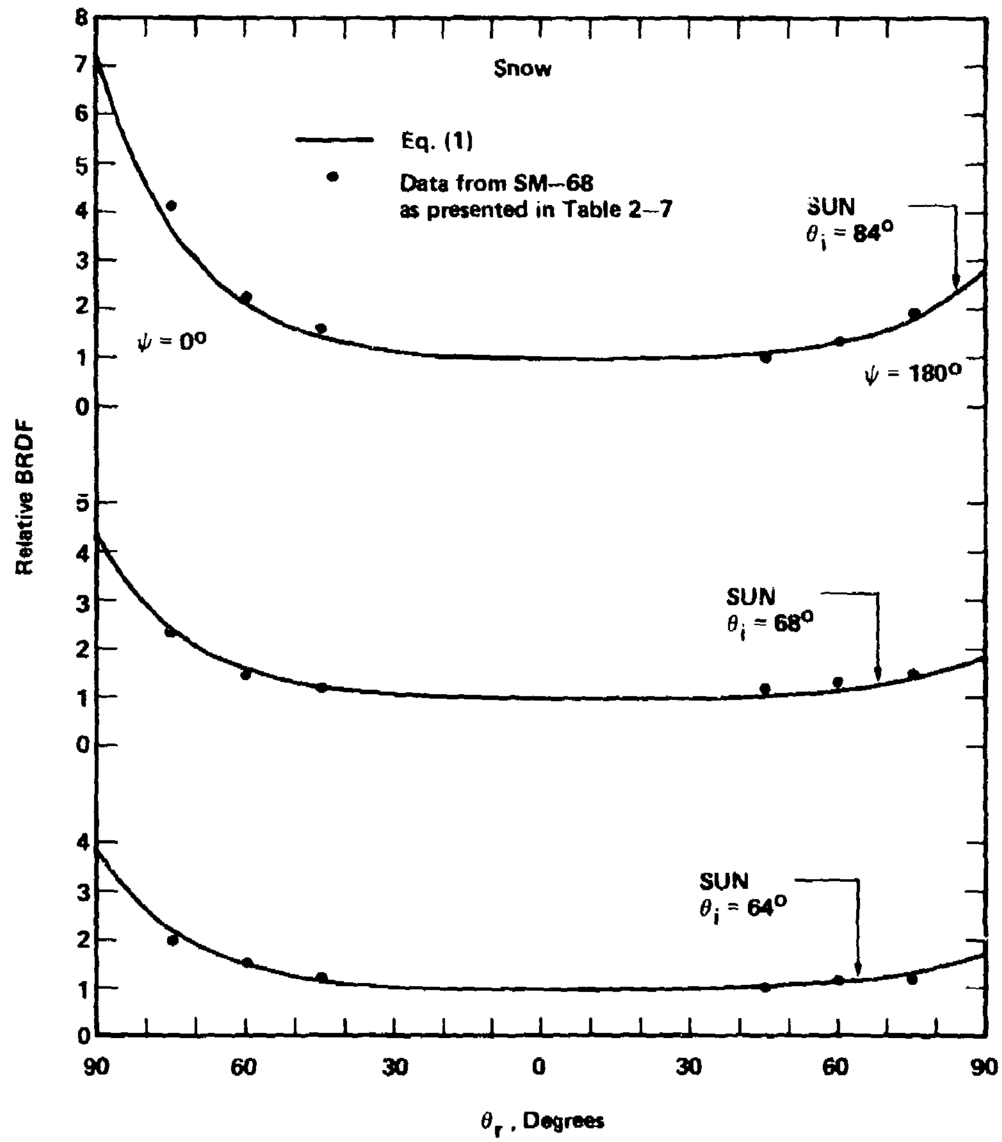


Figure 2–7. Relative BRDF for snow.

Table 2-8. Relative directional reflectance of gypsum sand for solar zenith angles of θ_i = 21, 48, 59 deg, in the spectral range 0.2 to 4.0 μm.[a]

Solar Zenith Angle θ_i	Azimuth Angle ψ	Zenith Angle of Reflected Ray, θ_r: 0	45	60	75
21	0	1.00	0.95	0.95	0.85
	180		1.04	1.04	0.95
48	0		1.00	1.02	1.04
	180		1.13	1.19	1.19
59	0		1.01	1.10	1.11
	180		1.11	1.22	1.28
59	0		1.04	1.07	1.38
	180		1.10	1.20	1.40

[a]Values inferred from Figures 17, 18, 9, and 19 of Salomonson and Marlatt [SM-68].

2-3.3 Soil

Coulson [Co-66a, Figure 4] plots the directional reflectance of black loam soil at three angles of incidence (0, 53, and 78.5 deg) in the principal plane for λ=6430 Å. Coulson notes that the backward maximum is relatively more pronounced at all three angles than it is for desert sand, and the forward maximum is almost absent at the small angles of incidence.

Duntley, Gordan, et al. [DG-64] measured the directional luminous reflectance of dirt (hard packed, yellowish). Their data are reproduced here in Table 2-9a. We have normalized these data to the nadir value and tabulated the results in Table 2-9b.

The expression we have evaluated as the relative BRDF for soil (dirt) is the ratio given by Equation (14) with the five directional parameters as given in Table 2-2a for m=5. We have plotted the results for the forward (ψ=0), backward ($\psi=\pi$), and sideward ($\psi=\pi/2$) directions as the set of continuous curves in Figure 2-9. The experimental values of DG-64 are also shown in Figure 2-9 for comparison.

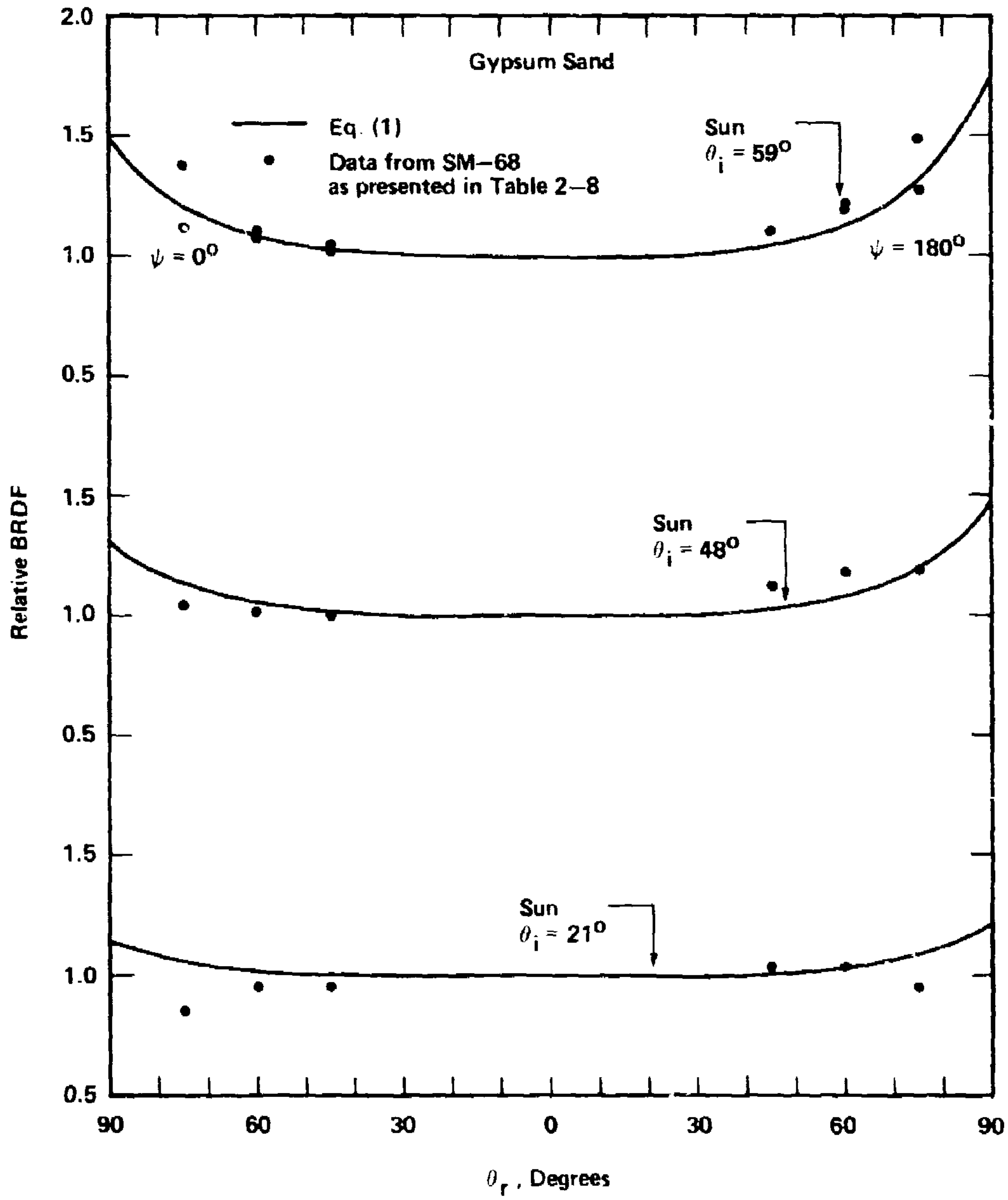


Figure 2–8. Relative BRDF for gypsum sand.

Table 2-9a. Directional luminous reflectance of dirt for solar zenith angles $\theta_i \approx 54$ deg.[a]

Solar Zenith Angle θ_i	Azimuth Angle ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75	80
53.2	0	0.243	0.230	0.229	0.239	0.252	0.300	0.330
56.5	90		0.243	0.258	0.260	0.276	0.300	0.304
51.1	180		0.272	0.313	0.370	0.422	0.432	0.434

[a]Duntley, Gordan et al. [DG-64, Table 3.2]; Item 8 = hard-packed, yellowish dirt.

Table 2-9b. Relative directional luminous reflectance of dirt for solar zenith angles $\theta_i \approx 54$ deg.[a]

Solar Zenith Angle θ_i	Azimuth Angle ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75	80
53.2	0	1.00	0.95	0.94	0.98	1.04	1.23	1.36
56.5	90		1.00	1.06	1.07	1.14	1.23	1.25
51.1	180		1.12	1.29	1.52	1.74	1.78	1.79

[a]Derived from Table 2-9a.

2-3.4 Vegetation

For green grass, Coulson [Co-66a] has measured the directional reflectance at four different wavelengths in the visible and near-IR spectral regions and at three different angles of incidence at λ=6430 Å, all measurements being in the principal plane.

Duntley, Gordan et al. [DG-64, Table 3.2] have measured the directional luminous reflectance of several types of vegetation. For each type of

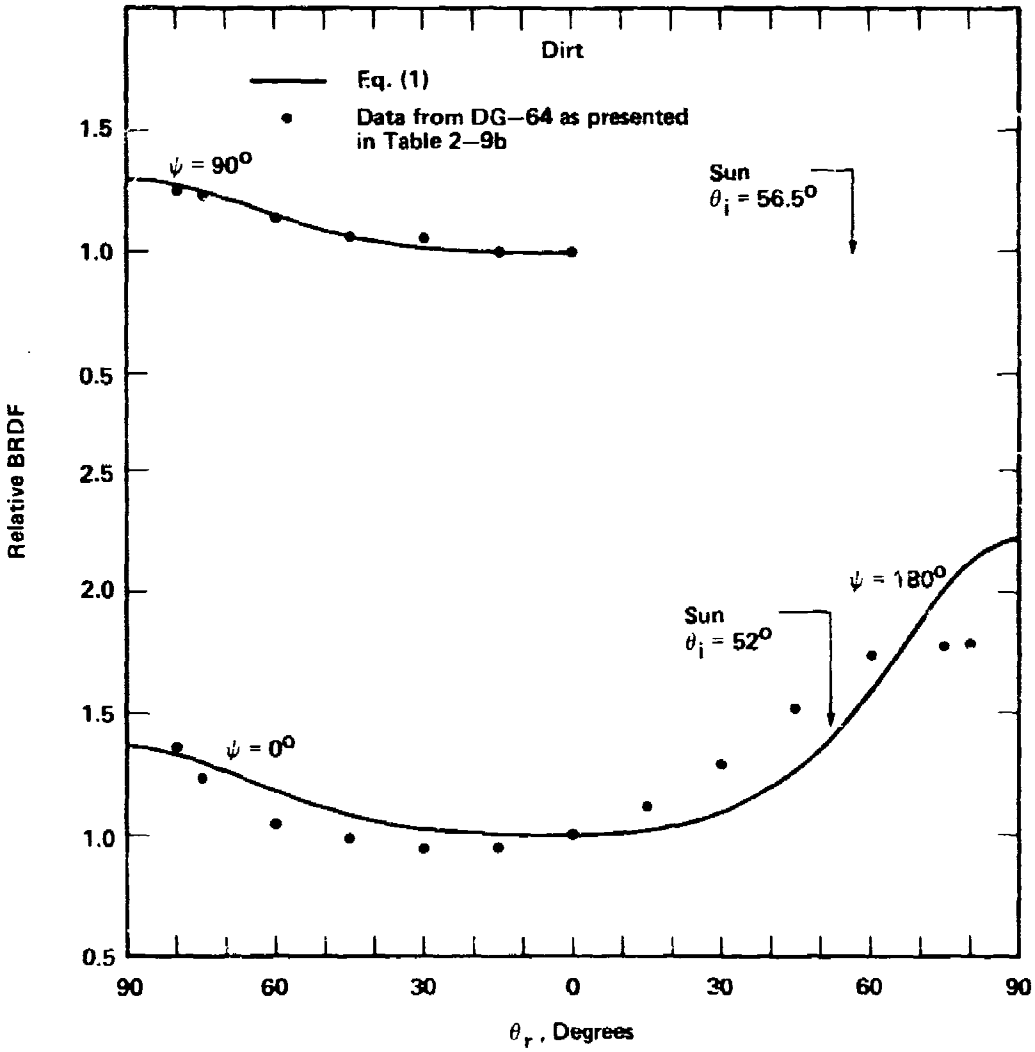


Figure 2–9. Relative BRDF for dirt.

vegetation we have normalized their data to the nadir value for the corresponding type of vegetation and presented the results in Table 2-10. The last set of numbers in Table 2-10 represents an average of the data for the first four types of vegetation.

The expression we have evaluated as the relative BRDF for vegetation is the ratio given by Equation (14) with the five directional parameters as given in Table 2-2a for m=6. We have plotted the results for the forward (ψ=0), backward ($\psi=\pi$), and sideward ($\psi=\pi/2$) directions as the set of continuous curves in Figure 2-10. The average of the experimental vegetation values, given in Table 2-10, are also shown in Figure 2-10 for comparison.

2-3.5 Urban Materials

2-3.5.1 Concrete and Asphalt

Wolfe [Wo-65a, pp. 88,89] presents directional reflectivity curves for concrete and for asphalt. In fact, results are given for three types of detectors: PbSe, PbS, and thermistor. We have selected the results for the PbSe detector as being of the greatest interest for applications in the 2- to 5-μm region, as seen by examining the detector characteristic curves presented by Wolfe [Wo-65a: PbSe, pp. 477-479; PbS, pp. 474-476; thermistor, p. 498]. We have digitized the directional reflectivity curves presented by Wolfe [Wo-65a] for the PbSe detector and taken account of the fact that the "directional reflectivity" r_{ir} given in these figures is related to the partial reflectance (which we here call the BRDF, f_r [Ni-70d, Ni-65c]) by the expression

$$r_{ir} = f_r(\theta_i,\theta_r;\psi=0,\pi) \cos\theta_i \cos\theta_r \quad . \tag{15}$$

We have given both the directly-read values r_{ir} and converted values f_r in Tables 2-11a and 2-11b. For each source zenith angle θ_i we have normalized these values of the BRDF to an average of the near-nadir values and tabulated the results in Table 2-11c.

Table 2-10. Relative directional luminous reflectance of several types of vegetation.

(1) Pine Trees; small, uniformly spaced. Data are for unresolved terrain.

Solar Zenith, θ_i	Azimuth ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75	80	85
41.5	0	1.00	0.72	0.64	0.64	0.78	1.14	1.39	2.58
	45		.67	.61	.58	.63	.91	1.16	1.65
	90		.95	.93	.95	.95	1.01	1.16	1.39
	135		1.01	1.15	1.18	1.16	1.32	1.39	1.72
	180		1.21	1.33	1.74	1.92	2.14	2.28	2.48

(2) Grass; thick, rather long, pale green, dormant, dryish, little ground showing.

Solar Zenith, θ_i	Azimuth ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75	80	85
41.5	0	1.00	0.92	0.86	0.87	1.00	1.07	1.09	1.07
	180		1.11	1.35	1.66	1.70	1.74	1.74	1.82

(3) Grass; lush green, closely mowed thick lawn.

Solar Zenith, θ_i	Azimuth ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75	80
40.4	0	1.00	0.96	0.98	1.08	1.20	1.49	1.68
39.6	90		1.03	1.10	1.21	1.38	1.59	1.68
39.6	135		1.07	1.25	1.48	1.66	1.78	1.78
39.9	180		1.09	1.09	1.19	1.22	1.25	1.25

(continued)

Table 2-10. Relative directional luminous reflectance of several types of vegetation (Cont'd).

(4) Mixed Green Forest; deciduous (oak) and evergeen (pine).

Solar Zenith, θ_i	Azimuth ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75
39.0	0	1.00	0.90	0.81	0.57	0.57	0.95
37.0	180		1.14	1.37	1.37	2.28	7.30

(5) Pine Forest.

Solar Zenith, θ_i	Azimuth ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75
33.5	0	1.00	1.00	0.80	0.64	0.64	0.52

(6) Average of First Four Types.

Solar Zenith, θ_i	Azimuth ψ	Zenith Angle of Reflected Ray, θ_r: 0	15	30	45	60	75	80	85
≈40	0	1.00	0.88	0.82	0.79	0.89	1.16	1.39	1.82
	90		0.99	1.01	1.08	1.16	1.30	1.42	
	180		1.14	1.28	1.49	1.78	3.11	1.76	

[a]From DG-64, Table 3.2

The expression we have evaluated as the relative BRDF for concrete and for asphalt is the ratio given by Equation (14) with the parameters for concrete being $\gamma_{7a} = 2$, $\alpha_{7a} = 4$, $\beta_{7a} = 0.5$, $R_{7a}(0) = 8$, and $R_{7b}(\pi) = 1$ and for asphalt being $\gamma_{7b} = 2$, $\alpha_{7b} = 4$, $\beta_{7b} = 0.5$ $R_{7b}(0) = 13$, and $R_{7b}(\pi) = 1$. We have plotted the results for the forward ($\psi=0$) and backward ($\psi=\pi$) directions in Figure 2-11a and 2-11b. The experimental values reported in Wo-65a are also shown in Figures 2-11a and 2-11b for comparison. For an average of con-

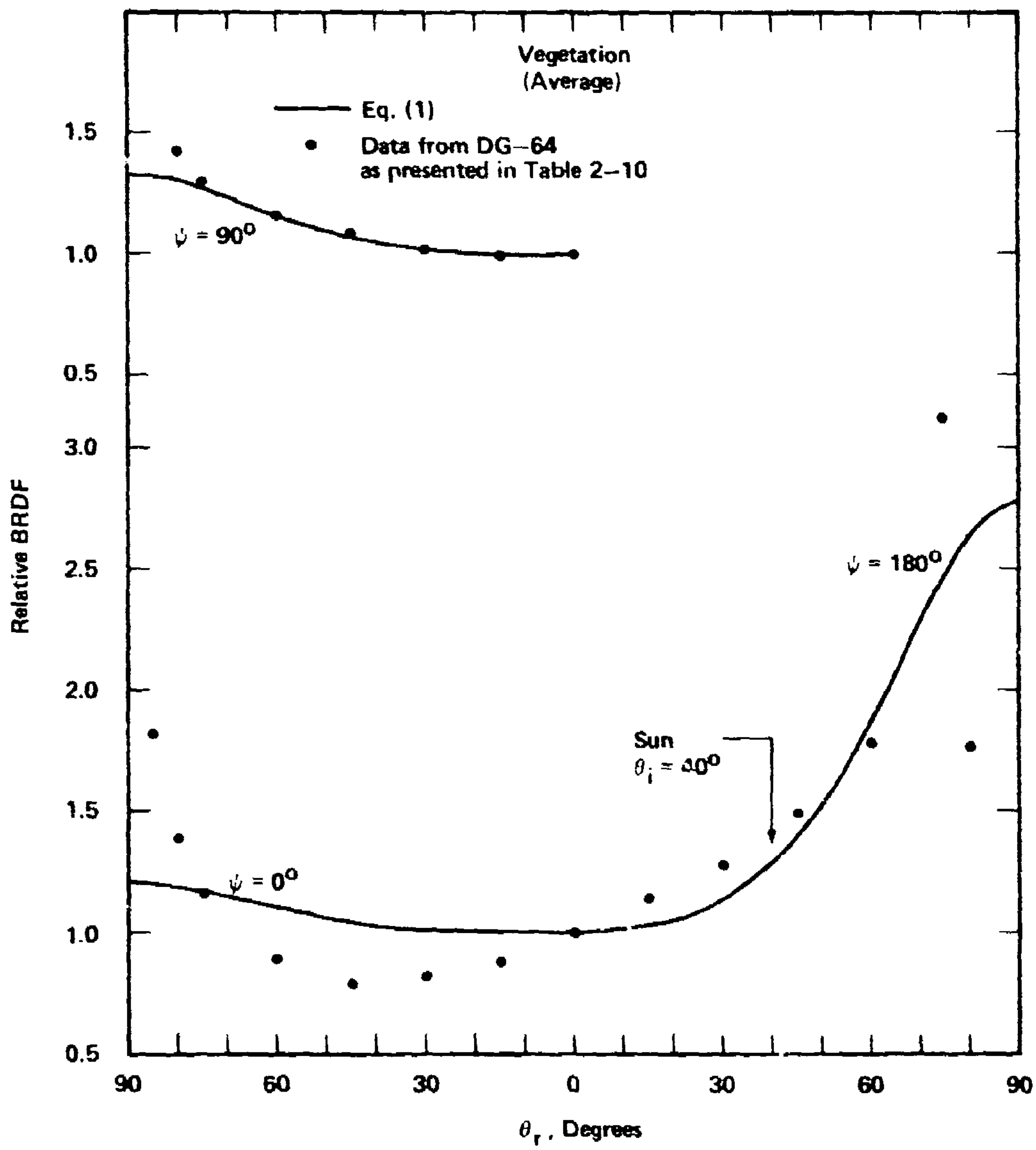


Figure 2–10. Relative BRDF for vegetation.

Table 2-11a. Directional reflectance data for concrete.[a]

ϕ	θ_r	r_{ir} $\theta_i=0$	r_{ir} $\theta_i=20$	r_{ir} $\theta_i=40$	r_{ir} $\theta_i=60$	f_r, sr^{-1} $\theta_i=0$	f_r, sr^{-1} $\theta_i=20$	f_r, sr^{-1} $\theta_i=40$	f_r, sr^{-1} $\theta_i=60$
0	80	0.027	0.030	0.030	0.032	0.16	0.18	0.23	0.37
0	70	.039	.040	.045	.055	.11	.12	.17	.32
0	60	.053	.053	.053	.064	.11	.11	.14	.26
0	50	.078	.075	.074	.061	.12	.12	.15	.19
0	40	.086	.081	.075	.057	.11	.11	.13	.15
0	30	.10	.094	.092	.058	.12	.12	.14	.13
0	20	.10	.11	.090	.053	.11	.12	.13	.11
0	10	.11	.12	.088	.059	.11	.13	.12	.12
	0		.11	.089	.064		.12	.12	.13
180	10	.10	.10	.084	.055	.10	.11	.11	.11
180	20	.10		.077	.049	.11		.11	.10
180	30	.10	.094	.073	.046	.12	.12	.11	.11
180	40	.087	.065		.049	.11	.090		.13
180	50	.073	.063	.053	.032	.11	.10	.11	.10
180	60	.061	.040	.050		.12	.085	13	
180	70	.037	.040	.030		.11	.12	.11	
180	80		.027				.17		

[a]Values of r_{ir} read from Wo-65a, p. 88, Figure 4-28, PbSe detector. Values of f_r computed from $f_r = r_{ir}/(\cos \theta_i \cos \theta_r)$.

crete and asphalt we propose the five directional parameters as given in Table 2-2a for m=7.

2-3.5.2 Urban Geometry Parameters

Because an urban area has an exceedingly complex geometrical structure, we introduce (1) a (conjectured) shadow-factor, $S(\theta_i,\theta_r)$, given by

$$S(\theta_i,\theta_r) = (\cos \theta_i + \cos \theta_r)/2 \qquad (1c)$$

(which may take on values in the range from 0 to 1 as θ_i and θ_r range from maximum values of $\theta_i = \theta_r = 90°$ to minimum values of $\theta_i = \theta_r = 0$), and (2) a

Table 2-11b. Directional reflectance data for asphalt.[a]

ψ	θ_r	r_{ir} $\theta_i=0$	$\theta_i=20$	$\theta_i=40$	$\theta_i=60$	f_r, sr^{-1} $\theta_i=0$	$\theta_i=20$	$\theta_i=40$	$\theta_i=60$
0	75			0.0093	0.015			0.047	0.12
0	70	0.0057	0.021	.014	.022	0.017	0.065	.053	.13
0	60	.025	.027	.020	.020	.050	.057	.052	.080
0	50	.025	.025	.020	.022	.039	.043	.041	.068
0	40	.025	.029	.023	.036	.032	.040	.039	.094
0	30	.028	.019	.027	.017	.032	.023	.041	.039
0	20	.020	.025	.031	.013	.021	.028	.043	.028
0	10	.026	.023	.022	.018	.026	.025	.029	.037
	0		.024	.022	.017		.025	.029	.034
180	10	.026	.022	.022	.011	.026	.024	.029	.022
180	20	.020		.018	.014	.021		.025	.030
180	30	.028	.014	.015	.014	.032	.017	.023	.032
180	40	.025	.026		.014	.032	.036		.037
180	50	.025	.025	.016	.012	.039	.041	.032	.037
180	60	.026	.013	.0069		.052	.028	.018	
180	70	.0066		.013	.0053	.019		.050	.031
180	80				.0036				.041

[a]Values of r_{ir} read from Wo-65a, p. 89, Figure 4-29, PbSe detector. Values of f_r computed from $f_r = r_{ir}/(\cos\theta_i \cos\theta_r)$.

degree-of-urbanization factor, D(7), with the range $0 \le D(7) \le 1$. The BRDF for an urban area will be defined as

$$\boxed{f_r(m=7) = D(7)\rho_{07}(\lambda)\, S(\theta_i,\theta_r) + [1-D(7)] \text{ [illegible] given by Eq. (1)].}} \quad (17)$$

Thus, for D(7) = 1, the spectral BRDF corresponds to a diffuse reflector modified by the shadow factor $S(\theta_i,\theta_r)$. For D(7)=0, the spectral BRDF corresponds to a flat surface with average directional-r[illegible]tance properties of concrete and asphalt.

The directional-hemispherical reflectance defined by Equation (5), with f_r given by Equation (17), is

Table 2-11c. Relative bidirectional reflectance distribution functions for concrete and asphalt.[a]

	Concrete					Asphalt				
ψ	θ_r	$\theta_i=0$	$\theta_i=20$	$\theta_i=40$	$\theta_i=60$	θ_r	$\theta_i=0$	$\theta_i=20$	$\theta_i=40$	$\theta_i=60$
0	80	1.45	1.50	1.92	3.25	75			1.62	3.97
0	70	1.00	1.00	1.42	2.81	70	0.72	2.60	1.83	4.30
0	60	1.00	0.92	1.17	2.28	60	2.13	2.28	1.79	2.65
0	50	1.09	1.00	1.25	1.67	50	1.66	1.72	1.41	2.25
0	40	1.00	0.92	1.08	1.32	40	1.36	1.60	1.34	3.11
0	30	1.09	1.00	1.17	1.14	30	1.36	0.92	1.41	1.29
0	20	1.00	1.00	1.08	0.96	20	0.89	1.12	1.48	0.93
0	10	1.00	1.08	1.00	1.05	10	1.11	1.00	1.00	1.22
	0		1.00	1.00	1.14	0		1.00	1.00	1.13
180	10	0.91	0.92	0.92	0.96	10	1.11	0.96	1.00	0.73
180	20	1.00		0.92	0.88	20	0.89		0.86	0.99
180	30	1.09	1.00	0.92	0.96	30	1.36	0.68	0.79	1.06
180	40	1.00	0.75		1.14	40	1.36	1.44		1.22
180	50	1.00	0.83	0.92	0.88	50	1.66	1.64	1.10	1.22
180	60	1.09	0.71	1.08		60	2.21	1.12	0.62	
180	70	1.00	1.00	0.92		70	0.81		1.72	1.03
180	80		1.42			80				1.36

[a]Derived from data in Tables 2-11a and 2-11b.

$$\langle\rho_7\rangle \equiv \langle\rho_7[\lambda;\theta_i,2\pi;\ D(7)]\rangle_{D(7)} = \int f_r \cos\theta_r \, d\Omega_r$$

$$= D(7)\ \rho_{07}(\lambda) \int S(\theta_i,\theta_r) \cos\theta_r \, d\Omega_r$$

$$+ [1-D(7)] \int [f_r \text{ given by Eq. (1)}] \cos\theta_r \, d\Omega_r$$

$$\langle\rho_7\rangle = D(7)\ \rho_{07}(\lambda)\ \frac{1}{2} \int (\cos\theta_i + \cos\theta_r) \cos\theta_r \, d\Omega_r$$

$$+ [1-D(7)]\ \pi\rho_{07}(\lambda)\ G(\alpha_7,\beta_7,\gamma_7;\theta_i)$$

$$\langle\rho_7\rangle = D(7)\ \rho_{07}(\lambda)\ \pi\ [\tfrac{1}{2}\cos\theta_i + \tfrac{1}{3}] + [1-D(7)]\ \rho_7(\lambda;\theta_i,2\pi). \tag{18}$$

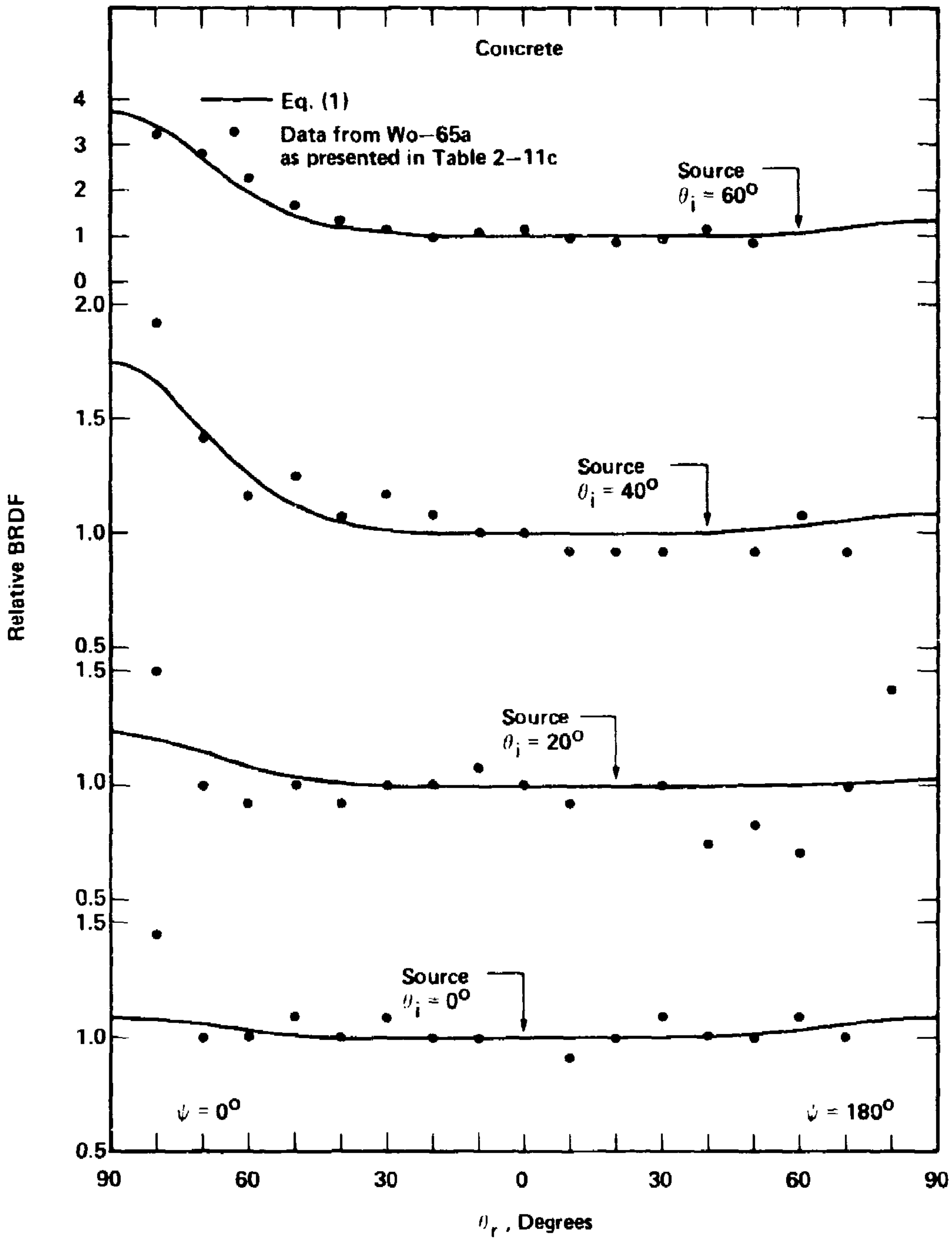


Figure 2–11a. Relative BRDF for concrete.

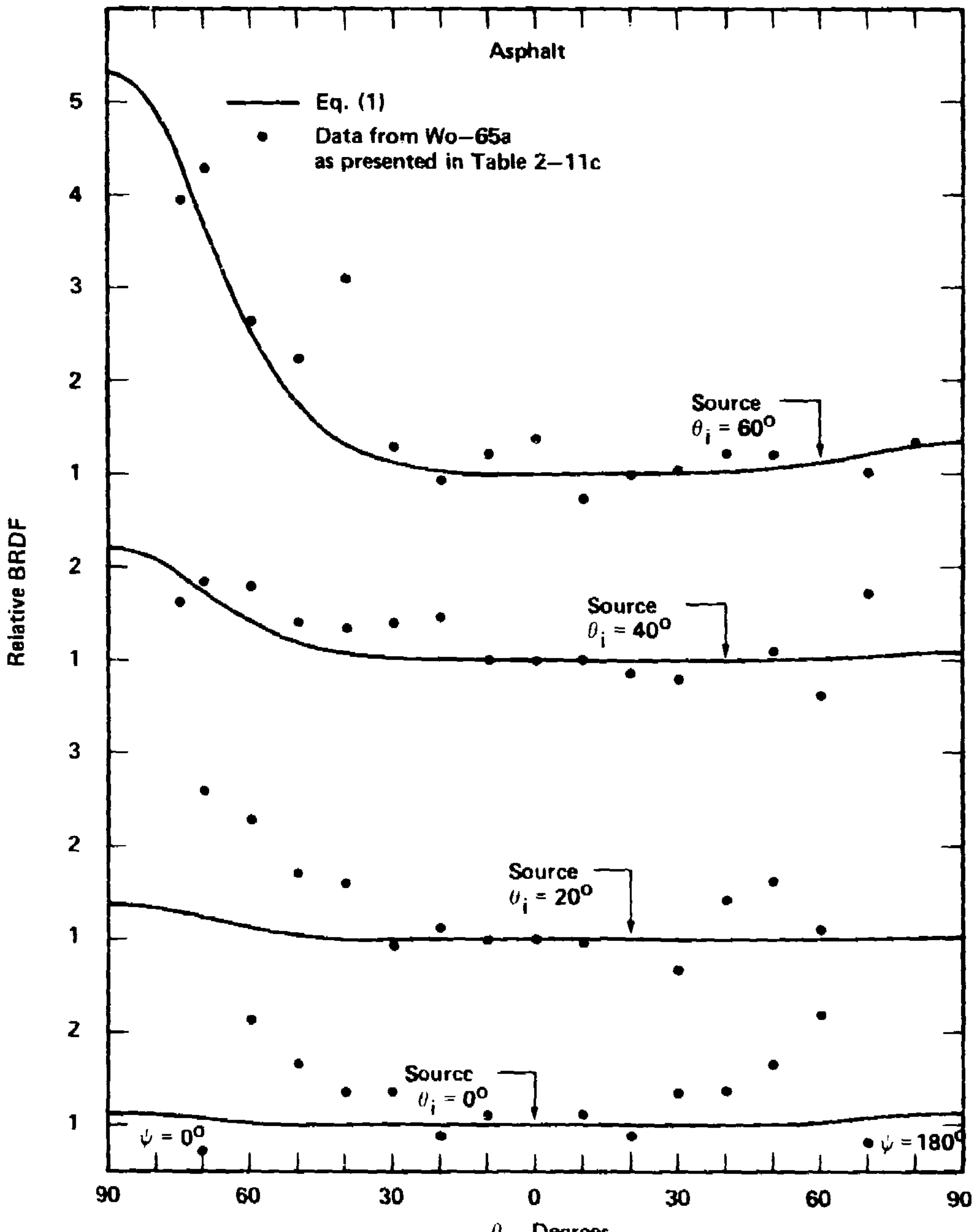


Figure 2–11b. Relative BRDF for asphalt.

The directional emissivity (for m=7, at a zenith angle θ) defined by Equation (12) with $\rho_m(\lambda;\theta,2\pi)$ given by $\langle\rho_7\rangle$ (in which θ_i is replaced by θ) is

$$\epsilon_d(m{=}7) \equiv \langle\epsilon_d[m{=}7,\lambda,\theta;D(7)]\rangle_{D(7)}$$

$$= 1 - \langle\rho_7\rangle \qquad (12'')$$

$$\boxed{\epsilon_d(m{=}7) = 1 - \left(\pi\ \rho_{07}(\lambda)\ D(7)\ [\frac{\cos\theta}{2} + \frac{1}{3}] + \rho_7(\lambda;\theta,2\pi)[1-D(7)]\right)} \qquad (19)$$

Thus, as expected, for D(7) = 1, the directional emissivity corresponds to that for a diffuse reflector modified by the shadow-factor quantity (which ranges from 1/3 for θ=90° to 5/6 for θ=0°). For D(7) = 0, the directional emissivity corresponds to a flat surface with average directional-emissivity properties of urban materials.

2-4 INTEGRATION OF THE BRDF

The spectral, directional-hemispherical reflectance, denoted here by $\rho(\theta_i,2\pi)$, is defined [Ni-65c, Wo-65a] by the integral

$$\rho(\theta_i,2\pi) = \int f_r \cos\theta_r\ d\Omega_r \qquad (5')$$

where f_r is the bidirectional reflectance-distribution function (BRDF). We want to evaluate this integral when f_r is given by our invented expression for the BRDF, given by Equation (1):

$$f_r \equiv f_r[m,\ D(m),\ \lambda;\ \theta_i,\ \theta_r,\ \psi] \equiv f_r(\theta_i;\ \theta_r,\ \psi) \qquad (20)$$

$$f_r = \rho_0[1 + F_\gamma(\theta_i)\ \Theta_r(\mu)\ \Psi(\psi)$$

with

$$F_\gamma(\theta_i) \equiv F_\gamma(\alpha,\theta_i) = \exp[-\alpha\ (\cos\theta_i)^\gamma] \qquad (21a)$$

$$\theta_r(\mu) = \exp[-\alpha\mu^\gamma] \tag{21b}$$

$$\mu = \cos\theta_r \tag{21c}$$

$$\Psi(\psi) = R(\psi)\,\exp[-\alpha\beta(1-|1-2\psi/\pi|)] \tag{21d}$$

$$R(\psi) = R(0) - \Delta R\psi/\pi \tag{21e}$$

$$\Delta R = R(0) - R(\pi)\ . \tag{21f}$$

For symmetry about the principal plane, we can write Equation (5') as

$$\rho(\theta_i,2\pi) = 2\rho_0 \int_0^\pi d\psi \int_0^1 d\mu\mu\ [1 + \exp(-\alpha\mu^\gamma)\Psi(\psi)F_\gamma(\theta_i)] \tag{22a}$$

$$= 2\rho_0[\frac{\pi}{2} + F_\gamma(\theta_i) \int_0^\pi d\psi\ \Psi(\psi)P_{2\gamma}(\alpha)] \tag{22b}$$

where

$$P_{2\gamma}(\alpha) \equiv \int_0^1 d\mu\mu\ \exp(-\alpha\mu^\gamma) \tag{23}$$

$$P_{21}(\alpha) = \frac{1}{\alpha^2}\,[1-e^{-\alpha}(\alpha+1)] \tag{23a}$$

$$P_{22}(\alpha) = \frac{1}{2\alpha}\,(1-e^{-\alpha})\ . \tag{23b}$$

For the ψ-integral, we have

$$I_\psi \equiv \int_0^\pi d\psi\ \Psi(\psi)$$

$$= \int_0^{\pi/2} d\psi\ \exp(-2\alpha\beta\psi/\pi)R(\psi) + \int_{\pi/2}^{\pi} d\psi\ \exp[-2\alpha\beta(\pi-\psi/\pi]R(\psi) \tag{24}$$

$$= R(0)\int_0^{\pi/2} d\psi\ \exp(-2\alpha\beta\psi/\pi) - \frac{\Delta R}{\pi}\int_0^{\pi/2} d\psi\ \psi\ \exp(-2\alpha\beta\psi/\pi)$$

$$+ R(0)\int_{\pi/2}^{\pi} d\psi\ \exp[-2\alpha\beta(\pi-\psi)/\pi] - \frac{\Delta R}{\pi}\int_{\pi/2}^{\pi} d\psi\ \psi\ \exp[-2\alpha\beta(\pi-\psi)/\pi] \tag{24a}$$

$$= R(0)\frac{\pi}{2}P_1(\alpha\beta) - \frac{\Delta R}{\pi}\left(\frac{\pi}{2}\right)^2 P_{21}(\alpha\beta) \tag{24b}$$

$$+ R(0)\frac{\pi}{2}P_1(\alpha\beta) - \frac{\Delta R}{\pi}\frac{\pi}{2}\left[\pi\ P_1(\alpha\beta) - \frac{\pi}{2}P_{21}(\alpha\beta)\right]$$

$$= \pi\bar{R}\ P_1(\alpha\beta) \tag{24c}$$

where

$$P_1(\alpha\beta) = \int_0^1 dy\ \exp(-\alpha\beta y) = \frac{1}{\alpha\beta}\left[1-\exp(-\alpha\beta)\right] \tag{25a}$$

$$\bar{R} = [R(0) + R(\pi)]/2\ . \tag{25b}$$

After collecting terms, we have

$$\rho(\theta_i, 2\pi) = \pi\rho_0 \left[1 + 2\, P_1(\alpha\beta)\, P_{2\gamma}(\alpha)\, \bar{R}\, F_\gamma(\alpha, \theta_i) \right] . \tag{26}$$

To compute $\langle f_r(0,0,\psi)\rangle$, we write

$$\langle f_r(0,0,\psi)\rangle \equiv \rho_0 \left[1 + F_\gamma(0)\, \theta_r(1)\, \langle\Psi(\psi)\rangle\right] \tag{27}$$

$$= \rho_0 \left[1 + \exp(-2\alpha)\, \langle\Psi(\psi)\rangle\right] \tag{27a}$$

with

$$\langle\Psi(\psi)\rangle = \frac{1}{\pi}\int_0^\pi d\psi\; \Psi(\psi) = \bar{R}\, P_1(\alpha\beta) . \tag{27b}$$

2-5 SUBROUTINE ESURF

Subroutine ESURF provides the bidirectional reflectance-distribution function (BRDF), directional emissivity, and temperature of the Earth's surface at the intersection point of the optical line-of-sight. Since the surface category is not automatically correlated with the geographic position, the user must select one of seven categories provided.

The relationship between Subroutine ESURF and the routines it calls is shown in Figure 2-12. Table 2-12 summarizes the inputs and outputs for Subroutine ESURF.

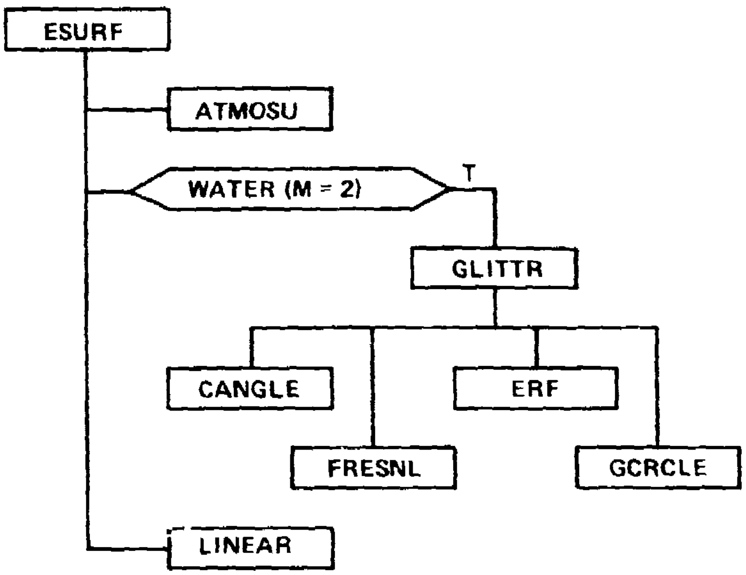


Figure 2– .2. Relationships between the routines in the Earth Surface Characterization Model.

Table 2-12. Input and output variables for Subroutine ESURF

INPUT VARIABLES

Argument List

THI - Zenith angle of sun at intersection point (P) on Earth's surface. (radians)

THR - Zenith angle of line-of-sight (from detector) at intersection point (P) on Earth's surface. (radians)

PSI - Azimuth angle (at intersection point (P)) of vertical plane through line-of-sight, measured relative to the solar principal plane (i.e., vertical plane through solar ray). A value of zero for PSI corresponds to forward scattering. (radians)

ZKM - Altitude of surface. (km)

MSM - Index M for category of surface material.
=1, Lambertian diffuse surface with spectrally-independent reflectance set by DD(1) and emissivity by [1 - DD(1)].
=2, Water.
=3, Snow.
=4, Sand.
=5, Soil.
=6, Foliage.
=7, Urban material.

DD(M) - Additional descriptor for selected surface material.

DD(1) = Diffuse reflectance for Lambertian surface. Typical value is 0.1.

DD(2) = Wind speed. (meters/sec)

DD(3) = Snow-age parameter, between the limiting values of 0 and 1 for new and old snow, respectively.

DD(M) for M = 4, 5, 6 not used.

(continued)

Table 2-12. Input and output variables for Subroutine ESURF (Cont'd).

	DD(7) =	Degree-of-urbanization between 0 and 1, for which limits the spectral BRDF corresponds, respectively, to (a) a flat surface with average directional-reflectance properties of concrete and asphalt and (b) a diffuse reflector multiplied by a shadow factor S(THI,THR)=[cos THI + cos THR]/2.
SPCULR -	Logical variable.	
	= .TRUE., Compute coordinates of specular reflection point on an assumed smooth horizontal water surface, if MSM = 2, in which case the variable is passed to Subroutine GLITTR.	
	= .FALSE., Do not compute such coordinates.	
ZLAM -	Wavelength. (μm)	
IDAY -	Index for diurnal condition at Point P.	
	= 0, Solar zenith angle > 90 deg.	
	= 1, Solar zenith angle $\leq$ 90 deg.	
IFIRES -	Flag for inclusion of fireballs as sources. In NBR Module, IFIRES = 0 always.	
	= 0, No fireball is to be considered.	
	> 0, Fireballs are to be considered.	
ESURF1 -	Logical variable.	
	= .TRUE., If ESURF is called for the first time from Subroutine SURRAD and both EPSD and TKS are wanted in addition to SFR as outputs. In NBR Module, ESURF1 = .TRUE. always.	
	= .FALSE., If ESURF is not being called for the first time from Subroutine SURRAD and a recomputation of EPSD and TKS is not needed. This possibility occurs only if Subroutine SURRAD is used as a utility routine with fireballs as sources.	

(continued)

Table 2-12. Input and output variables for Subroutine ESURF (Cont'd).

ATMOUP Common

TT - Ambient atmospheric temperature at altitude ZKM. (deg K)

OUTPUT VARIABLES

Argument List

SFR - Bidirectional reflectance-distribution function.

= f_r[M, DD(M), ZLAM; THI, THR, PSI]. (1/sr)

EPSD - Directional emissivity

= 1 - ρ_m(ZLAM; THR, 2π). (dimensionless)

TKS - Surface temperature. (deg K)

POSITN Common

(This output obtains only if MSM=2 and SPCULR=.TRUE.)

SPCLAT, SPCLON - North latitude and east longitude of the point on an assumed smooth horizontal surface for a specular reflection from the sun to the detector at Point V. (radians)

SECTION 3

EARTH SURFACE CHARACTERIZATION: WATER SURFACE

3-1 RADIANCE FROM A WIND-RUFFLED WATER SURFACE

3-1.1 Basic Cox-Munk Formula

The Cox-Munk formula [CM-54, Equation (9)] may be rewritten as

$$\boxed{L_{CM} \equiv L \equiv N = \frac{\rho(\omega)}{4} \frac{E\ p(\beta)}{\cos\mu\ \cos^4\beta}} \tag{1}$$

where L is the spectral radiance of the sea surface in the line-of-sight, $\rho(\omega)$ is the Fresnel specular reflectance of water for radiation of wavelength λ at angle of incidence ω, μ is the zenith angle of the detector, β is the slope (or tilt) of the water facet required to give a specular reflection to the detector, E (called H in CM-54) is the solar spectral irradiance (normal to the solar path) at the sea surface, and $p(\beta)$ is the probability for the occurrence of slope β.

Stegelmann and Garvey [SG-73b] derive an equation for the radiance which differs from Equation (1). The ratio of the radiance predicted by Stegelmann and Garvey to that predicted by Cox and Munk is

$$\frac{L_{SG}}{L_{CM}} = \frac{\cos\theta_i \cos\beta}{\cos\omega}, \tag{2}$$

where θ_i is the solar zenith angle. Stegelmann and Garvey seem to imply that Equation (1) is incorrect owing to an incorrect coordinate transformation. We have not checked all of the work in detail, so we don't know what the discrepancies are due to. Since the Cox-Munk formula is widely used in the litera-

ture, we will continue to use it until the cause of the alleged error is identified more explicitly.

3-1.2 Slope Distribution Function

Cox and Munk [CM-54] show that to a first order the slopes are normally distributed and independent of wind direction, according to

$$p = \frac{1}{\pi\sigma^2} \exp[-(z_x^2 + z_y^2)/\sigma^2] \tag{3a}$$

where

σ = rms slope regardless of direction

α = azimuth of the direction of steepest ascent, measured clockwise from the sun

$$z_x = \partial z/\partial x = \sin\alpha \tan\beta \tag{4a}$$

$$z_y = \partial z/\partial y = \cos\alpha \tan\beta \tag{4b}$$

so that

$$\boxed{p = \frac{1}{\pi\sigma^2} \exp(-\sigma^{-2} \tan^2 \beta).} \tag{3b}$$

3-1.3 Relation Between Slope Variance and Wind Speed

3-1.3.1 Cox-Munk Relation (regardless of direction)

Cox and Munk [CM-54, CM-56] computed the mean square slope components, for crosswind (σ_c^2) and up/downwind (σ_u^2), from their glitter photographs. For simplicity we shall use only their results for the mean square slope, $\sigma^2 = \sigma_c^2 + \sigma_u^2$, regardless of wind direction, for a clean surface (as opposed to an oil-slick surface, e.g.)·

$$\sigma^2 = \sigma_c^2 + \sigma_u^2 = (3 + 5.14\ W) \times 10^{-3} \pm 0.004. \tag{5}$$

This result is based on measurements for wind speeds from about 0.8 to about 14 m/sec [CM-56].

Since one might expect σ to vanish as W vanishes, we have plotted the velocity-dependent portion of Equation (5),

$$\sigma_0 = (0.00512\ W)^{1/2}\ , \tag{5a}$$

as the dash-dot line in Figure 3-1. We also represent Equation (5) in Figure 3-1 by plotting

$$\sigma = (\sigma_0{}^2 + 0.003)^{1/2} \tag{5b}$$

as the solid line and

$$\sigma_{\pm} = (\sigma^2 \pm 0.004)^{1/2} \tag{5c}$$

as the dashed lines.

3-1.3.2 Some Useful Wind-Related Conversion Factors

Relations between knots, meters per second, and miles per hour are:

1 knot = 0.5144 m/sec = 1.151 mph.

Relations between sea-states, Beaufort numbers, and wind velocity are shown in Figure 3-2 (adapted from Wu-69a).

There is a significant altitude variation of wind which must be kept in mind while reading the sun-glitter literature.

Duntley [Du-54], in relating his measurements of the distribution of water wave slopes (on a lake) to those of Cox and Munk [CM-54] (in the open

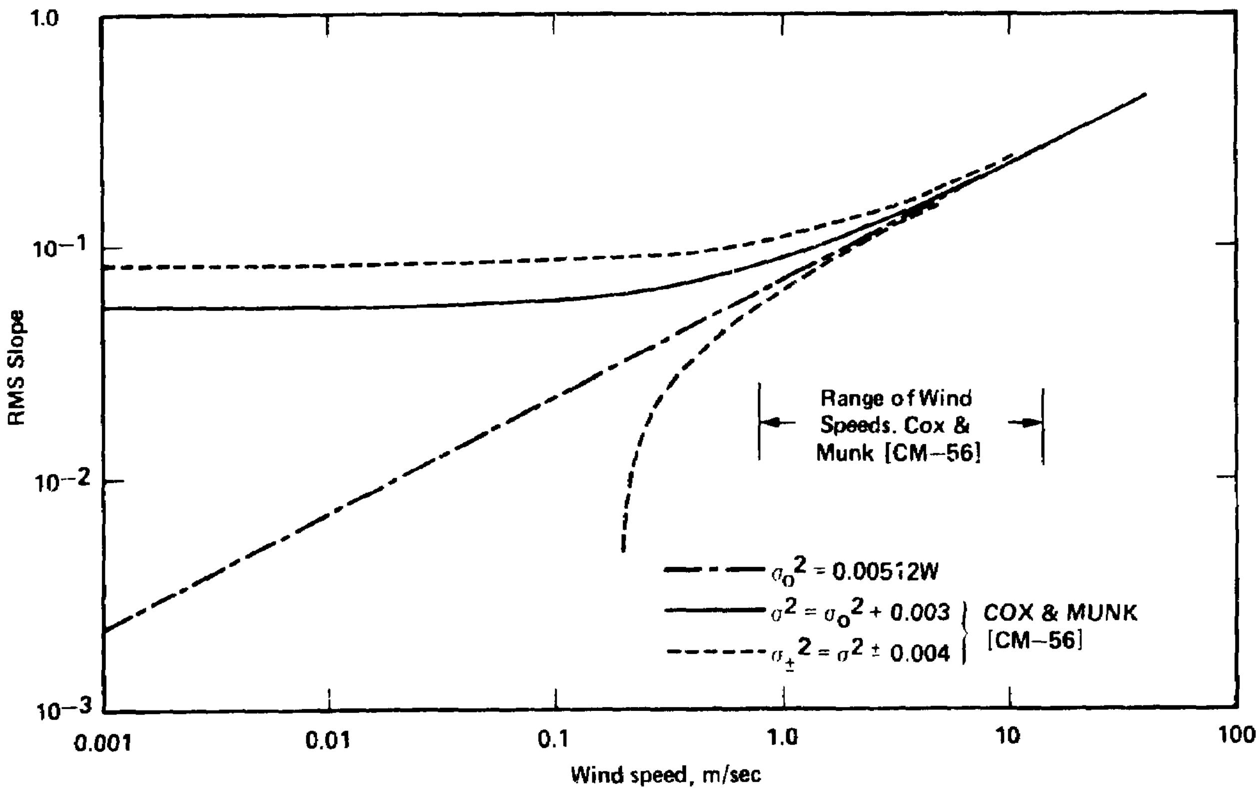


Figure 3–1. Relation between RMS slope and wind speed.

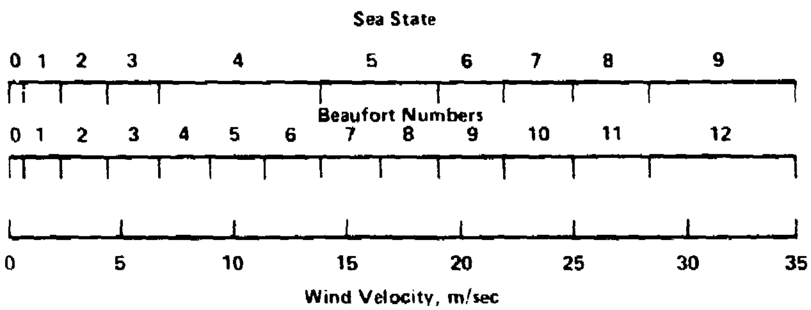


Figure 3–2. Relations between sea-states, Beaufort numbers, and wind speed (from Wu–69a).

sea), speaks of the "customary 2-to-1 ratio between wind speeds measured at 41 feet (12.5 meters) above the mean water level (as for CM-54) and 8 inches [Du-54] above the wave crests."

Cox [Co-58] relates his laboratory measurements to those of Cox and Munk [CM-54]. Cox states:

> "Measurements of wind speed in the tank represent average speed throughout the air channel; it may be estimated that the level at which this speed is reached in the boundary layer next to the water is 4 to 8 cm above mean water level. Hence, oceanic measurements of wind speeds made at a height of 12.5 m must be reduced by a large and uncertain correction factor before a useful comparison can be made. I assume the factor is
>
> $$\ln\left[\left(\frac{6.0}{0.1}\right)\Big/\left(\frac{1.25 \times 10^4}{0.1}\right)\right] = 2.2;$$
>
> this assumes (1) a logarithmic velocity profile near the water in both tank and ocean, (2) an effective height of wind

observation in the tank of 6 cm, and (3) a roughness length in both the tank and ocean of 0.1 cm."

3-1.3.3 Limitations on the Cox-Munk Relation

Strong and Ruff [SR-70a] state: "Recent results from Wu [J. Atmos. Sci. 26, 408 (1969)] show a sea-roughness saturation for winds above 15 m/sec, which means one cannot rely on a changing slope distribution at higher wind speeds."

Time does not permit further review of the relation between slope variance and wind speed; some additional relevant references include those by Wu [Wu-69a, Wu-70, Wu-71, Wu-72a, Wu-77] and Cox [Co-74].

3-2 REFLECTION GEOMETRY FOR A SPHERICAL EARTH

Cox and Munk assumed a flat Earth in deriving their reflection geometry. We want to consider a spherical Earth. Fortunately, Levanon [Le-71b] has derived the necessary equations for viewing the reflections from a synchronous satellite. We have not yet verified the equations in detail; so far, we have only determined, by examining Levanon's simplified formulas, that an east longitude relative to the detector is positive and a north latitude is positive. Levanon assumed his satellite was on the equator and at zero-degree longitude. Accordingly, we have modified some of his definitions so as to allow for an arbitary position of the detector. We reproduce these (slightly modified) definitions and formulas from Levanon's Section 2 [Le-71b]. Anyone studying these equations should consult his Figure 2 which illustrates the reflection geometry.

Levanon has considered the following geometrical question: Given the longitude and latitude of the sun and detector subpoints, and of the point of reflection, what is the tilt magnitude and direction and the angle of incidence, at that point of reflection?

The following notation is adopted:

O	-	the center of the Earth
S	-	the sun subpoint
V	-	the detector
P	-	the point of reflection
i	-	an index taking values s, p, $\vec{\ell}$, $\vec{n}$
Q_i	-	a point defined by the sea surface and a vector parallel to i and starting at O
θ_i	-	north latitude of i (or of Q_i)
ϕ_i	-	east longitude of i (or of Q_i) relative to that of V
r	-	radius of Earth
h_d	-	altitude of detector
h_p	-	altitude of P (if a lake, e.g.)
$\vec{\ell}$	-	vector between the detector and the point of reflection
$\vec{n}$	-	the normal required for reflection from P
θ	-	the northward tilt at P
ϕ	-	the eastward tilt at P
β	-	the magnitude of the total tilt at P
ω	-	the angle of incidence

For convenience we introduce

$$\epsilon_d = (r + h_p)/(r + h_d).$$

For Point Q_ℓ:

$$\phi_\ell = \tan^{-1}\left[\frac{-\epsilon_d \cos\theta_p \sin\phi_p}{1-\epsilon_d \cos\theta_p \cos\phi_p}\right] \quad (L1)$$

$$\theta_\ell = \tan^{-1}\left[\frac{-\epsilon_d \sin\theta_p}{(1-2\,\epsilon_d \cos\theta_p \cos\phi_p + \epsilon_d^2 \cos^2\theta_p)^{1/2}}\right]. \quad (L2)$$

For Point Q_n:

$$\phi_n = \tan^{-1}\left[\frac{\cos\theta_\ell \sin\phi_\ell + \cos\theta_s \sin\phi_s}{\cos\theta_\ell \cos\phi_\ell + \cos\theta_s \cos\phi_s}\right] \tag{L3}$$

$$\theta_n = \tan^{-1}\left[\frac{\sin\theta_\ell + \sin\theta_s}{[\cos^2\theta_\ell + \cos^2\theta_s + 2\cos\theta_\ell \cos\theta_s \cos(\phi_\ell - \phi_s)]^{1/2}}\right] \tag{L4}$$

At the point of relection the tilt toward the east is given by

$$\phi = \phi_n - \phi_p \tag{L5}$$

and the tilt toward the north by

$$\theta = \theta_n - \theta_p. \tag{L6}$$

Since ϕ and θ are orthogonal, the total tilt magnitude is

$$\beta = \tan^{-1}[\tan^2\theta + \tan^2\phi]^{1/2} \tag{L7}$$

and the angle of incidence is

$$\omega = \tan^{-1}[\tan^2(\theta_n - \theta_s) + \tan^2(\phi_n - \phi_s)]^{1/2}. \tag{L8}$$

In Table 3-1 we have summarized the input and output quantities, based on Levanon's equations.

3-3 REFLECTANCE AND EMISSIVITY

3-3.1 The Bidirectional Reflectance-Distribution Function (BRDF)

The BRDF is defined as

Table 3-1. Input and output quantities for reflection viewed from a detector.

Input Quantities (per Levanon)		
Object	**East Longitude**	**North Latitude**
Sun subpoint (S)	ϕ_s	θ_s
Detector subpoint (V')	$\phi_v=0$	$\theta_v=0$
Reflection point (P)	ϕ_p	θ_p

Intermediate Output Quantities		
Quantity	**Symbol**	**Le-71b Eq. No.**
Longitude of Q_ℓ	ϕ_ℓ	1
Latitude of Q_ℓ	θ_ℓ	2
Longitude of Q_n	ϕ_n	3
Latitude of Q_n	θ_n	4
Eastward tilt at P	ϕ	5 (9)[b]
Northward tilt at P	θ	6 (10)[b]

Final Output Quantities		
Quantity	**Symbol**	**Le-71 Eq. No.**
Tilt magnitude at P	β	7 (11)[b]
Angle of incidence at P	ω	8 (12)[b]

[a]Values relative to detector subpoint V'.

[b]For small-angle approximation, which we do not use.

$$f_r = L/(E \cos \theta_i) \tag{6}$$

where L is the radiance along the reflected ray and $E \cos \theta_i$ is the irradiance on the (horizontal) sea surface. By using the Cox-Munk formula, Equation (1), for L/E, we have

$$f_r = \frac{\rho(\omega)}{4} \frac{p(\beta)}{\cos \mu \cos^4 \beta \cos \beta_i} . \tag{7}$$

(It is not obvious that Equation (7) satisfies the reciprocity law, since β and ω have a very complicated dependence on the coordinates.)

3-3.2 The Directional-Hemispherical Reflectance

The directional-hemispherical reflectance, denoted here by $\rho(\lambda;\theta_i, 2\pi)$, is defined by the integral

$$\rho(\lambda;\theta_i,2\pi) = \int f_r \cos \theta_r \, d\Omega_r \tag{8}$$

with f_r given by Equation (7); it is understood that

$$\mu \equiv \cos \theta_r . \tag{9}$$

Owing to the complexity of the dependence of ω and β on θ_r, we assume it is impossible to perform an analytic integration indicated in Equation (8).

For now, we shall not pursue further the topic of directional-hemispherical reflectance for a wind-ruffled sea. We were interested in it mainly as a self-consistent way to get the directional emissivity, but we shall content ouselves with an approximate treatment as next described.

3-3.3 The Directional Emissivity

Since we are unable to perform an analytic integration of the BRDF to get the directional-hemispherical reflectance for a wind-ruffled sea, we shall ignore the wind and compute the directional emissivity from the expression (sometimes referred to as Kirchhoff's law)

$$\boxed{\varepsilon_d(\theta) = 1 - \rho(\theta)} \tag{10}$$

where $\rho(\theta)$ is the Fresnel specular reflectance next discussed in Section 3-3.4.

We note that Hall [Ha-64b] used Equation (10) for each of the planes of polarization of the radiation in computing the polarized emissivity of (flat and calm) water. We expect that Equation (10) will provide reasonable answers even for a wind-ruffled sea except for large zenith angles. Perhaps one can later make an improvement for such large zenith angles. Papers by Saunders [Sa-67a, Sa-68c] may be helpful.

3-3.4 Fresnel Reflectance of Water

3-3.4.1 Introduction

The factor $\rho(\omega)$ in the Cox-Munk formula, Equation (1), is the Fresnel specular reflectance of water for unpolarized radiation incident on a plane surface at angle of incidence ω. The Solar Radiation Model (23e), described in Section 4, provides E_λ (at the top of the atmosphere). Here, we present the Fresnel equations necessary to compute $\rho(\omega)$ and necessary data for the complex index of refraction for an air-water interface.

3-3.4.2 Formulas

We need the formula for the reflectance $\rho(\omega)$ of a plane electromagnetic wave incident at an angle $\theta_i \equiv \omega$ on a plane, absorbing surface (water). For an unpolarized wave, and a complex index of refraction N,

$$N = n - ik, \tag{11}$$

where n is the index of refraction, k is the extinction coefficient, and $i = \sqrt{-1}$, the monochromatic specular reflectance is given [Me-60a, p.422; AH-66; SC-66a, p.63] by the expression

$$\boxed{\rho(\omega) = r_s \frac{c + d^2}{c + 2a_+ d + d^2}} \tag{12}$$

where

$$r_s = (c - 2a_+ e + e^2)/(c + 2a_+ e + e^2) \tag{13a}$$

$$c = a_+^2 + a_-^2 \tag{13b}$$

$$d = \sin\omega \tan\omega \tag{13c}$$

$$e = \cos\omega \tag{13d}$$

$$2\,a_\pm^2 = [(n^2 - k^2 - \sin^2\omega)^2 + 4n^2k^2]^{1/2} \pm (n^2 - k^2 - \sin^2\omega)\ . \tag{13e}$$

At normal incidence,

$$\rho(0) = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}\ . \tag{14}$$

We chose the Fresnel formulas as given by Equations (12) and (13) because (1) the form is the simplest we have seen and (2) three different references agree on the formulas. (Note that Me-60a uses $N = n(1-ik)$ instead of $N = n - ik$.) Relatively simple, but different formulas are given by Friedman [Fr-69b] but the two obvious misprints leaves one uncomfortable without verifying the overall formulas. Hall [Ha-64b] also gives the Fresnel formulas but

their form is again different and more complicated than that we have chosen. Other references include Condon and Odishaw [CO-58, 6-8, 6-113,-114], Stratton [St-41], and Born and Wolf [BW-75a]. Boudreau [Bo-73b] gives the Fresnel formulas in a form attributed to Stratton [St-41].

3-3.4.3 Complex Index of Refraction of Water

The most recent values of optical constants for (pure) water in the infrared are those given by Downing and Williams [DW-75] who tabulate $n(\nu)$ and $k(\nu)$, the real and imaginary parts of the complex index $N = n + ik$, in the range from λ=2 μm to λ = 1 mm. In the 2- to 5-μm range of interest to us, 221 sets of data are given for wavenumbers ν=2000(10)4000(50)5000, entered as data statements in Subroutine FRESNL.

We also note that very recently Querry et al. [QH-77] determined the complex refractive index in the infrared for samples of surface water from five widely separate locations: San Francisco Bay, the Pacific Ocean, the Atlantic Ocean, the Great Salt Lake (Utah), and the Dead Sea (Israel). The variations will be ignored for the purposes of ROSCOE-IR.

3-4 SLOPE-SHADOWING FACTOR

Cox and Munk [CM-55, p. 70; CM-56, p. 470], in computing the albedo of direct sunlight from a rough surface, take account of the fact that large negative slopes in the component z_y (where the y-azis is horizontally away from the sun) are shadowed if they exceed cot θ_i, with θ_i the solar zenith angle. Cox and Munk include this effect by setting the limits to be (-cot θ_i) and ($+\infty$) for z_y (but $\pm\infty$ for z_x). Thus, while Cox and Munk include the effect in their albedo calculation, they do not mention the effect with respect to the slope distribution function $p(\beta)$ appearing in Equation (1).

Gordan [Go-69b] presents a formula, derived by K. B. MacAdam, for the fraction of the light from a source at zenith angle θ_i which reaches a given point on the sea surface without having first intersected the water surface at some other point. However, in presenting his formula, Gordan [Go-69b, p.20]

fails to note that the derivation is based on a one-dimensional distribution (instead of an isotropic, two-dimensional distribution as we would like). Also, Gordan [Go-69b] does not address the question of shadowing effects on the reflected ray.

Saunders [Sa-67a, Sa-68c] has derived an approximate, slope-shadowing factor, S^*, to account for the fact that, as one views near the horizon, the slopes on the back sides of the waves and deep in the troughs are hidden. For two-dimensional roughness, the factor S^* is stated [Sa-67a, p. 4648; Sa-68c] to be

$$S^*(\theta_r) = 2 \{1 + \mathrm{erf}(v) + \frac{1}{v\sqrt{\pi}} e^{-v^2} \}^{-1} \tag{15a}$$

where v, given by

$$v = \sigma^{-1} \tan (\frac{\pi}{2} - \theta_r) = \sigma^{-1} \cot \theta_r, \tag{15b}$$

is the ratio of the inclination of the line-of-sight to the root-mean-square slope (regardless of direction) and θ_r is the zenith angle of the reflected ray. Presumably $S^*(\theta_r)$ refers to only the reflected ray not escaping in one pass.

To permit a "bistatic" dependence on the zenith angles of both the incoming and outgoing rays, we propose using as the shadow factor

$$S(\theta_i,\theta_r) = S(\theta_i)\, S(\theta_r) \tag{16}$$

with

$$S(\theta) = 2 \{1 + \mathrm{erf}(v) + \frac{1}{v\sqrt{\pi}} e^{-v^2} \}^{-1} \tag{17a}$$

$$v = \sigma_s \cot \theta \qquad (17b)$$

$$\sigma_s = (5.12 \times 10^{-3}\ W)^{1/2}\ . \qquad (17c)$$

For numerical reasons, we need to consider some limiting cases:

(a) If the wind speed $W = 0$, we set $S(\theta_i, \theta_r) = 1.0$.

(b) If $\theta < \theta_{v2} \equiv \tan^{-1}(0.5\ \sigma_s^{-1})$, we set $S(\theta) = 1.0$. The introduction of the angle θ_{v2} results from the observation that the shadowing factor is essentially unity for $v \gtrsim 2$. Thus, there is no need to compute the shadowing factor unless θ exceeds the angle (θ_{v2}) for which $v=2$, for a given wind speed.

(c) If $(0.5\pi - \theta) < 1.745 \times 10^{-3}$, set θ to 89.9 deg, an arbitrarily selected value. We do this to avoid possible division by zero or near-zero.

3-5 SPECIAL CASES

3-5.1 Location of Specular Point for Quiet Surface (no wind) on Spherical Earth, Given Locations of Source and Detector

Since we want to consider cases where the Earth-central angle between rays to the sun and the detector is not necessarily small, we cannot use the "lens" equation for a spherical convex mirror (and the concomitant paraxial rays) to aid in determining the reflection point but must resort to an iterative solution.

3.5.1.1 Algebraic Equations for Specular Point

Assume we are given the positions (i.e., the longitudes and latitudes of the subpoints) of the detector and sun, as depicted in Figure 3-3 (Points V' and S', respectively). The total central angle between the rays OV and OS, α, is given by

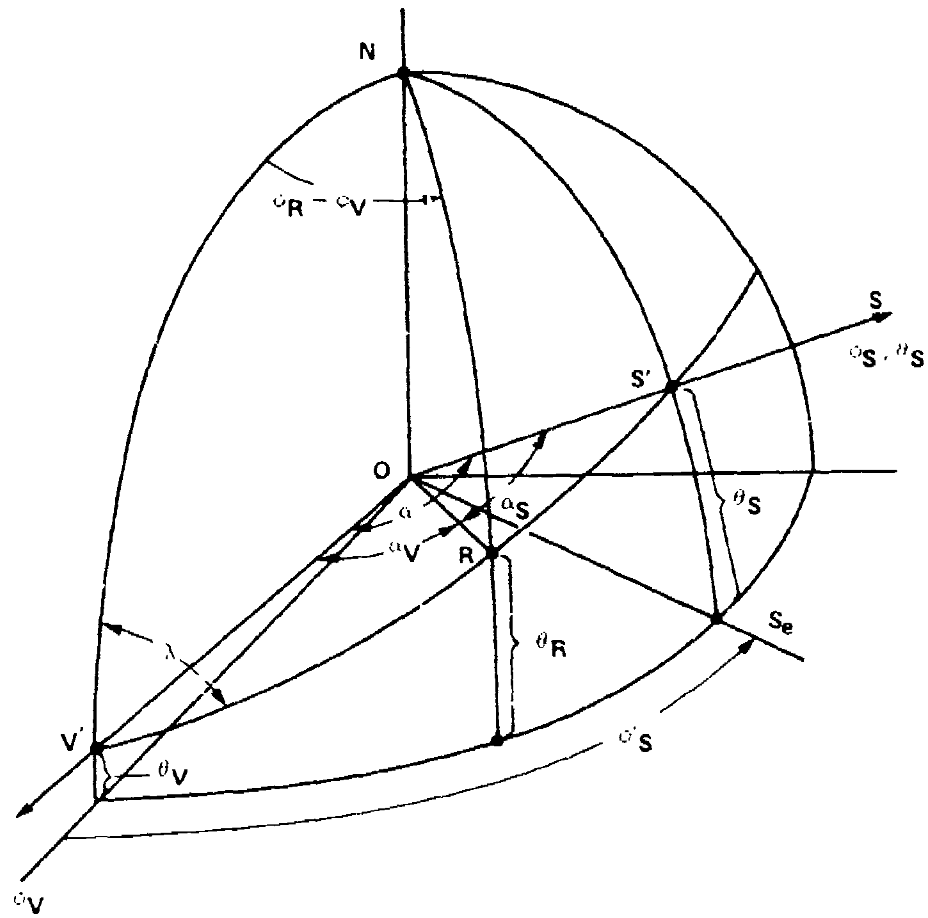


Figure 3–3. Spherical geometry for determining specular point.

$$\alpha = \cos^{-1} (\sin \theta_s \sin \theta_v + \cos \theta_s \cos \theta_v \cos \phi'_s) \tag{18}$$

$$\phi'_s = \phi_s - \phi_v \; . \tag{18a}$$

In the VOS plane, in which the reflection point, R, must lie, consider the plane triangles ORV and ORS, depicted in Figure 3-4. The sum of the two central angles, α_v and α_s, must equal α, i.e.,

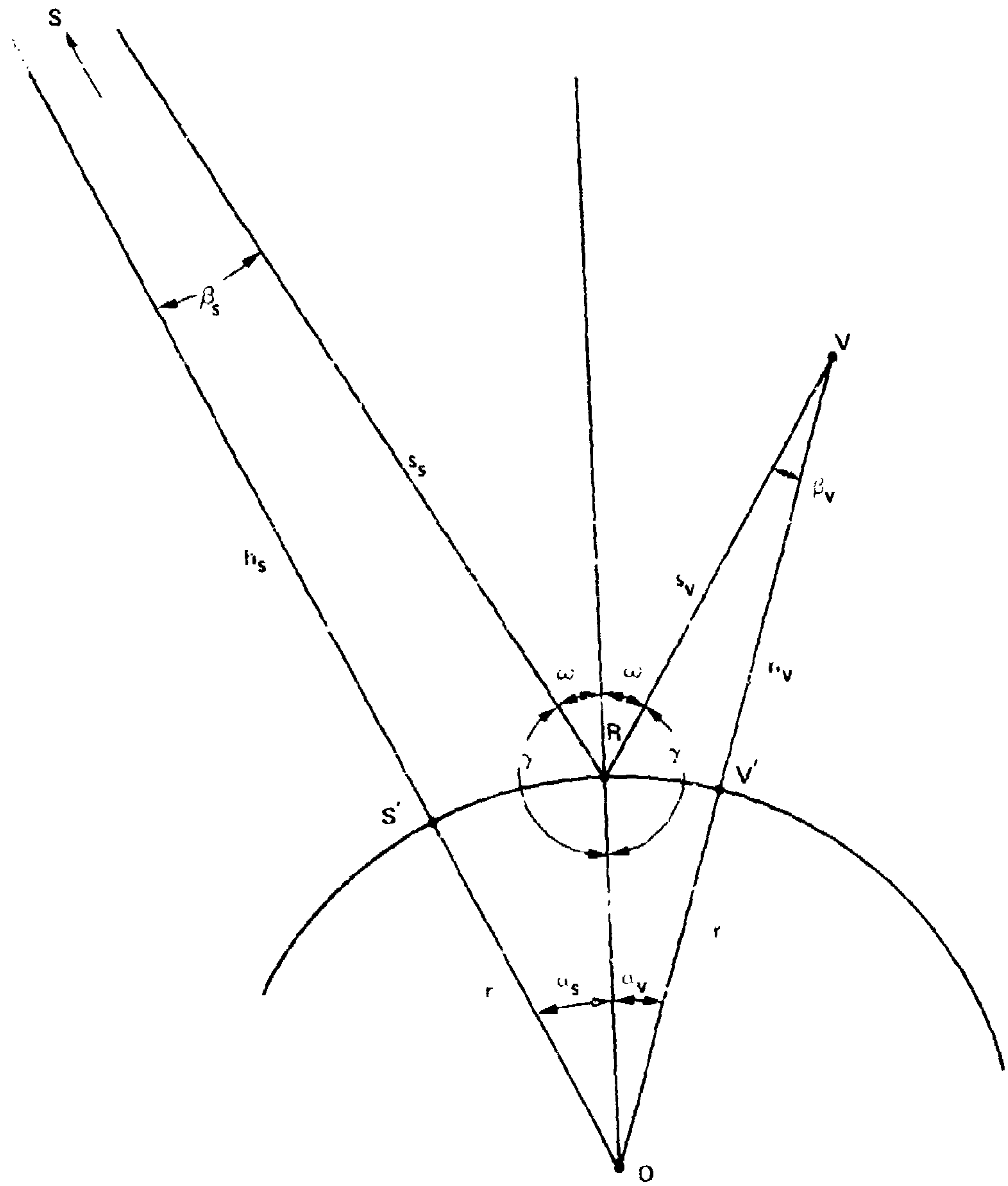


Figure 3–4. Plane geometry for determining specular point

$$\boxed{\alpha_v + \alpha_s = \alpha\ ,} \tag{19}$$

and for each triangle, we have

$$\alpha_v + \beta_v + \gamma = \pi \tag{20a}$$

$$\alpha_s + \beta_s + \gamma = \pi\ . \tag{20b}$$

Thus, from Equations (20a) and 20b), we have

$$\boxed{\alpha_v + \beta_v = \alpha_s + \beta_s\ .} \tag{21}$$

Now,

$$r_v \equiv r + h_v = r \cos \alpha_v + s_v \cos \beta_v \tag{22a}$$

$$r_s \equiv r + h_s = r \cos \alpha_s + s_s \cos \beta_s \tag{22b}$$

and

$$\frac{s_v}{\sin \alpha_v} = \frac{r}{\sin \beta_v} = \frac{r_v}{\sin \gamma} \tag{23a}$$

$$\frac{s_s}{\sin \alpha_s} = \frac{r}{\sin \beta_s} = \frac{r_s}{\sin \gamma}\ . \tag{23b}$$

(In the code, r is the Earth radius plus the altitude assigned to the Point P.) By eliminating s_v between Equations (22a) and (23a) and s_s between Equations (22b) and (23b), we get

$$r_v = r \cos \alpha_v + r \frac{\sin \alpha_v}{\sin \beta_v} \cos \beta_v \tag{24a}$$

$$r_s = r \cos \alpha_s + r \frac{\sin \alpha_s}{\sin \beta_s} \cos \beta_s \tag{24b}$$

or

$$\epsilon_v^{-1} \equiv \rho_v \equiv \frac{r_v}{r} = \cos \alpha_v + \sin \alpha_v / \tan \beta_v \tag{24c}$$

$$\epsilon_s^{-1} \equiv \rho_s \equiv \frac{r_s}{r} = \cos \alpha_s + \sin \alpha_s / \tan \beta_s \tag{24d}$$

or

$$\boxed{\begin{aligned} \beta_v &= \tan^{-1} [\epsilon_v \sin \alpha_v (1-\epsilon_v \cos \alpha_v)^{-1}] \qquad (24e) \\ \beta_s &= \tan^{-1} [\epsilon_s \sin \alpha_s (1-\epsilon_s \cos \alpha_s)^{-1}] \, . \qquad (24f) \end{aligned}}$$

Thus we have four equations ((19), (21), (24e), and (24f)) which need to be solved for the four unknowns (α_v, α_s, β_v, and β_s).

In presenting the equations for the specular point we have referred to the sun as the source. Indeed, that is the case within the NBR Module. However, in the original development of the specular point equations, we wanted to allow for non-solar sources at arbitrary altitudes, for which our specular-point equations are valid.

If one does specialize for a solar source, then one can obtain (with an appropriate approximation) a pair of equations (or, equivalently, a single transcendental equation if the user prefers) instead of the set of four equations. That is, for a solar source, as in Section 5-3.2.1 where we obtain the

solar zenith angle, we can assume that the solar ray to the reflection point is essentially parallel to the ray to the subsolar point, an approximation implying that the angle β_s is essentially zero. Thus, in Equation (21), if we set β_s equal to zero and eliminate α_s by use of Equation (19), we obtain

$$\alpha_v = (\alpha - \beta_v)/2 \; . \tag{24g}$$

Thus we have two equations ((24e) and (24g)) which need to be solved for the two unknowns (α_v and β_v). Of course, one can eliminate α_v between these two equations if he prefers. An iterative solution of the pair of equations should be analogous to that described in Section 3-5.1.2, but we have not implemented such a solution.

3-5.1.2 Iterative Solution of Specular-Point Equations

By using Equations (19), (21), (24e), and (24f), we find the condition to be satisfied is

$$F(\alpha_v) \equiv \alpha - 2\alpha_v + \tan^{-1}\left[\frac{\epsilon_s \sin \alpha_s}{1-\epsilon_s \cos \alpha_s}\right] - \tan^{-1}\left[\frac{\epsilon_v \sin \alpha_v}{1-\epsilon_v \cos \alpha_v}\right] = 0 \; . \tag{25}$$

Now,

$$\frac{dF(\alpha_v)}{d\alpha_v} \equiv F'(\alpha_v) = -2 + \frac{\epsilon_s^2 - \epsilon_s \cos \alpha_s}{1+\epsilon_s^2 - 2\epsilon_s \cos \alpha_s} + \frac{\epsilon_v^2 - \epsilon_v \cos \alpha_v}{1+\epsilon_v^2 - 2\epsilon_v \cos \alpha_v} \; . \tag{26}$$

According to the Newton-Raphson method, our iteration formula is

$$\alpha_v^{(n+1)} = \alpha_v^{(n)} - \frac{F(\alpha_v^{(n)})}{F'(\alpha_v^{(n)})} \; . \tag{27}$$

It remains to choose a starting value, $\alpha_v^{(0)}$, to be used in Equation (27). To do so, we start with Equation (21) and substitute for β_v and β_s their small-angle approximations from Equations (24e) and (24f). Thus we get

$$\alpha_v + \frac{\epsilon_v \alpha_v}{1-\epsilon_v} = \alpha - \alpha_v + \frac{\epsilon_s(\alpha-\alpha_v)}{1-\epsilon_s} \quad . \tag{28}$$

By solving Equation (28) for α_v in terms of α, ϵ_v, and ϵ_s, we get

$$\alpha_v = \left[\frac{1-\epsilon_v}{(1-\epsilon_v) + (1-\epsilon_s)}\right]\alpha \quad . \tag{29}$$

Our iterative procedure now becomes

$$\alpha_v^{(0)} = \left[\frac{1-\epsilon_v}{(1-\epsilon_v) + (1-\epsilon_s)}\right]\alpha \tag{29a}$$

$$\alpha_s^{(0)} = \alpha - \alpha_v^{(0)} \tag{30a}$$

$$\beta_v^{(0)} = \text{From Equation (24e)} \tag{30b}$$

$$\beta_s^{(0)} = \text{From Equation (24f)} \tag{30c}$$

$$F(\alpha_v^{(0)}) = \text{From Equation (25)} \tag{30d}$$

$$F'(\alpha_v^{(0)}) = \text{From Equation (26)} \tag{30e}$$

$$\alpha_v^{(1)} = \alpha_v^{(0)} - \frac{F(\alpha_v^{(0)})}{F'(\alpha_v^{(0)})} . \tag{30f}$$

We now put $\alpha_v^{(1)}$ into Equation (30a) and continue the looping over Equations (30) until we satisfy the condition

$$\alpha_v^{(n)} + \beta_v^{(n)} - (\alpha_s^{(n)} + \beta_s^{(n)}) \equiv \delta^{(n)} \leq 2 \times 10^{-5} . \tag{31}$$

3-5.1.3 Angle of Incidence and Reflection

From Figure 3-4 and Equation (20a), we have

$$\omega = \pi - \gamma = \alpha_v + \beta_v , \tag{32}$$

with α_v and β_v given by the iterative solution in Section 3-5.1.2.

3-5.1.4 Geographic Coordinates of Specular Point

Determination of the geographic coordinates of the specular point, given those for the sun and detector and the central angles α and α_v, is provided by Subroutine GCRCLE, discussed in Section 3-6.5.

3.5-2 Radiance and BRDF for Specular Reflection from Smooth Water

To obtain the radiance for specular reflection from a smooth water surface, one can follow, e.g., the detailed development (given for another purpose) by Cox and Munk [CM-54] or immediately write the answer by assuming conservation of radiance for reflection from a perfect reflector. For the latter alternative we have for the specular radiance

$$L_{spec} = \rho(\omega)E/(\pi\varepsilon^2) \tag{33}$$

where $\rho(\omega)$ and E are the same as in Equation (1) and ε is the angular radius of the sun (16.0 minutes).

The BRDF corresponding to Equation (33) is defined to be

$$f_r = L_{spec}/(E \cos \theta_i) \tag{34}$$

so that

$$f_r = \rho(\omega)/(\pi\epsilon^2 \cos \theta_i) \ . \tag{34a}$$

3-5.3 A Limiting Form of Basic Cox-Munk Formula

The Cox-Munk basic formula, Equation (1), explicitly including the formula for the probability for the occurrence of slope β, is

$$L_{CM} = \frac{\rho(\omega)}{4} \frac{E}{\cos \mu \cos^4 \beta} \frac{\exp(-\sigma^{-2} \tan^2 \beta)}{\pi\sigma^2} \ . \tag{35}$$

For a zenith sun and downward-looking detector, the slope is zero and the zenith angle of the reflected ray equals the angle of incidence, i.e.,

$$\beta = 0$$
$$\mu = \omega = 0,$$

so that

$$L_{CM}(\beta=0) = \frac{\rho(0)}{4} \frac{E}{\pi\sigma^2} \ . \tag{36}$$

We note that this radiance is smaller than the specular value given by Equation (33) by the ratio

$$\boxed{\frac{L_{CM}(\beta=0)}{L_{spec}} = \left[\frac{\epsilon}{2\sigma}\right]^2 \ ,} \tag{37}$$

since

$$\left[\frac{\epsilon}{\sigma}\right]^2 = \frac{(4.65 \times 10^{-3})^2}{(3 + 5.12W) \times 10^{-3}} \ll 1 \ . \tag{38}$$

The ratio given by Equation (37) will be obtained in another way in Section 3-5.4.

3-5.4 Relation Between Radiances from Smooth- and Rough-Water Surfaces

Saunders [Sa-67, p. 4116] makes a simple estimate of the radiance reflected from a rough-water surface compared with that from a smooth-water surface. He notes that the angular radius of the glitter pattern is approximately 2σ (as is readily seen from Figure 3-5) and hence the solid angle it subtends is $\pi(2\sigma)^2$, where σ is the root-mean-square slope. The solid angle subtended by the mirror image of the sun is [according to Saunders] $\pi\epsilon^2$, where ϵ is the angular radius of the sun's disk. (Saunders did not account for the solid angle of the mirror image of the sun being reduced for an observer at high altitudes, as explained below.) Saunders then states that if the total radiant energy reflected from the surface is independent of roughness (an assumption commented upon below), then the ratio of the intensity in the glitter pattern to the intensity in the mirror image is in the inverse ratio of the solid angles that they subtend, namely, $(\epsilon/2\sigma)^2$. Note that this ratio is just the ratio given by Equation (37).

A smooth-water surface on the spherical Earth acts like a convex spherical mirror of radius R_e. The virtual image of the sun is formed at a depth $R_e/2$ below the surface and the size of the sun's radius in this image is $\epsilon R_e/2$. The area of the virtual image is $\pi(\epsilon R_e/2)^2$ and the solid angle at the observer, at an altitude h from the mirror surface, is

$$\Omega = \pi \frac{(\epsilon R_e/2)^2}{(h + R_e/2)^2} = \pi\epsilon^2 \left[\frac{R_e/2}{h + R_e/2} \right]^2 \tag{39}$$

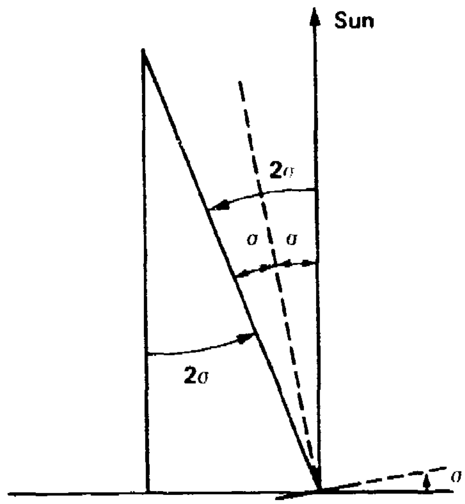


Figure 3–5. Geometry for simple estimate of angular radius of glitter pattern.

$$\rightarrow \begin{cases} \pi\epsilon^2 & \text{for } h \to 0 \qquad (39a) \\ \pi\epsilon^2 \, (R_e/2h)^2 & \text{for } h \gg R_e/2 \, . \qquad (39b) \end{cases}$$

The assumption made above by Saunders - that the total radiant energy reflected from the surface is independent of the roughness - is adequate for the order-of-magnitude estimate being made but it is not strictly correct. Cox and Munk [CM-55, Section 3; CM-56] show that the albedo of a rough surface to direct sunlight is slightly larger at high sun angles and substantially smaller at low sun angles than the albedo of a flat surface.

3-6 SUBROUTINES FOR CHARACTERIZATION OF WATER SURFACE

The relationship between the routines characterizing a water surface and Subroutine ESURF (for non-water surface characterization) is shown in Figure 2-12.

3-6.1 Subroutine GLITTR

Subroutine GLITTR is called from Subroutine ESURF when the line-of-sight from the detector (either a fictitious one at Point V in the NBR Module or, more generally, a real detector which may be in a satellite) intersects a wind-ruffled water surface prescribed by the user. Subroutine GLITTR provides (1a) the bidirectional reflectance-distribution function (BRDF) for the wind-ruffled water surface and (1b) the directional emissivity of a smooth-water surface as an approximation to that for the wind-ruffled water surface at the intersection (Point P) of the optical line-of-sight from the detector and, if requested (by the logical variable SPCULR = .TRUE. in the argument list), (2) the geographical coordinates of the point on an assumed smooth horizontal surface (taken to be at the same altitude as Point P) for a specular reflection of a ray from the source to the detector. Only the directional emissivity at Point P is provided if there is no source.

See Table 3-2 for a summary of inputs and outputs for Subroutine GLITTR and Figure 3-6 for a chart of information flow within Subroutine GLITTR.

3-6.2 Function CANGLE

Function CANGLE is called from Subroutines RINOUT and GLITTR to compute the Earth-central angle, CANGLE, between two central rays to Points P1 and P2, given the latitudes and longitudes of Points P1 and P2. Application of the cosine law for a side of the spherical triangle P1-N-P2 in Figure 3-7 gives the relation

$$\cos a_{12} = \cos\left(\frac{\pi}{2}-\theta_1\right) \cos\left(\frac{\pi}{2}-\theta_2\right) + \sin\left(\frac{\pi}{2}-\theta_1\right) \sin\left(\frac{\pi}{2}-\theta_2\right) \cos\left(\phi_2-\phi_1\right)$$

Table 3-2. Input and output variables for Subroutine GLITTR.

INPUT VARIABLES

Argument List

THETI - Zenith angle of the source at the intersection point (P) of the line-of-sight from the detector to the Earth's water surface. (radians)

WIND - Wind speed at 41 feet above sea level. (meters/sec)

SPCULR - Logical variable.

= .TRUE., Compute coordinates of specular reflection point for an assumed smooth surface.

= .FALSE., Do not compute such coordinates.

ZLAM - Wavelength. (μm)

IDAY - Index for diurnal conditions at Point P.

= 0, Solar zenith angle >90 deg.
= 1, Solar zenith angle $\leq$90 deg.

IFIRES - Flag for inclusion of fireballs as sources.

= 0, No fireball is being considered (always the case in the NBR Module).

> 0, Fireballs are being considered as sources.

ESURF1 - Logical variable.

= .TRUE., If Subroutine ESURF is called for the first time from Subroutine SURRAD and EPSD is wanted as an output (always the case in the NBR Module).

= .FALSE., If Subroutine ESURF is not being called for the first time from Subroutine SURRAD and a recomputation of EPSD is not needed.

TECTOR Common

DETALT, DETLAT, DETLON - Detector (at Point V) altitude, north latitude, and east longitude. (km, radians, radians)

(continued)

Table 3-2. Input and output variables for Subroutine GLITTR (Cont'd).

DETZEN	-	Detector (at Point V) zenith angle at Point P. (radians)

POSITN Common

POSALT, POSLAT, POSLON	-	Altitude, north latitude, and east longitude of intersection on Earth's surface (Point P) of line-of-sight from detector (at Point V). (km, radians, radians)

SOURCE Common

SRCALT	-	Altitude of source, if not the sun. (km)
SRCLAT, SRCLON	-	North latitude and east longitude of source (sun in NBR Module, or fireball, more generally). (radians)
SRCFLG	-	Flag characterizing source. = 1, Sun is source (always, in NBR Module). = 2, Fireball is source (never, in NBR Module).

OUTPUT VARIABLES

Argument List

SFR	-	Bidirectional reflectance-distribution function for a wind-ruffled water surface at Point P. (sr^{-1})
EPSD	-	Directional emissivity (of a smooth-water surface as an approximation to that for a wind-ruffled surface) at Point P toward the detector at Point V. (dimensionless)

POSITN Common

(This output obtains only if SPCULR = .TRUE.)

SPCLAT, SPCLON	-	North latitude and east longitude of the point on an assumed horizontal surface for a specular reflection from the source to the detector at Point V. (radians)

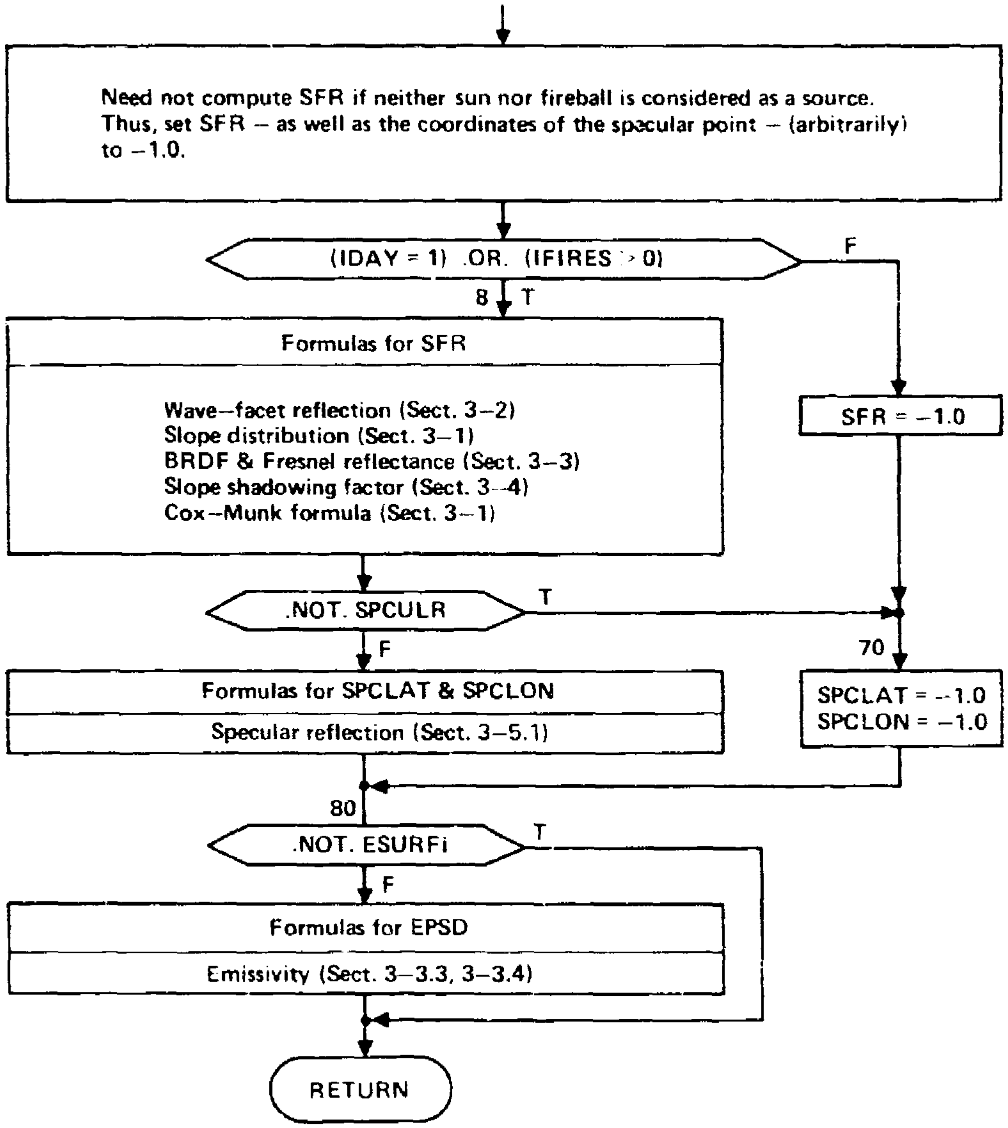


Figure 3–6. Information flow within Subroutine GLITTR

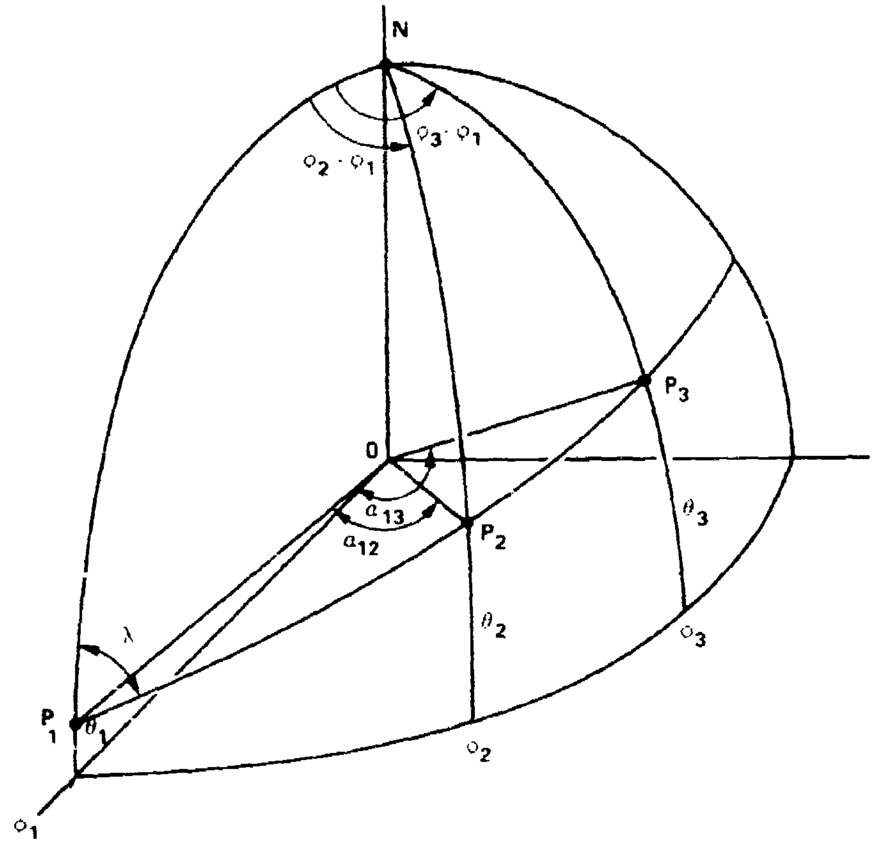


Figure 3–7. Earth geometry used in deriving formulas for Function CANGLE and Subroutine GCRCLE.

$$\cos \alpha_{12} = \sin \theta_1 \sin \theta_2 + \cos \theta_1 \cos \theta_2 \cos (\phi_2 - \phi_1)$$

or

$$\text{CANGLE} = \alpha_{12}$$

$$= \cos^{-1} [\sin P1LAT \sin P2LAT + \cos P1LAT \cos P2LAT \cos (P2LON-P1LON)] .$$

See Table 3-3 for a summary of inputs and outputs for Function CANGLE.

Table 3-3. Input and output variables for Function CANGLE.

INPUT VARIABLES		
Argument List		
P1LAT, P1LON	-	North latitude and east longitude of Point P_1. (radians)
P2LAT, P2LON	-	North latitude and east longitude of Point P_2. (radians)
OUTPUT FUNCTION		
CANGLE	-	Earth-central angle between rays to Points P_1 and P_2. (radians)

3-6.3 Function ERF

Function ERF is the error function, based on the rational-approximation formula (7.1.2.6) in AS-64.

3-6.4 Subroutine FRESNL

Fresnel specular reflectance of a (smooth) water surface is discussed in Section 3-3.4. In Subroutine FRESNL, the complex index of refraction of water as given by Downing and Williams [DW-75] is stored as data and the Fresnel reflectance is computed from Equations (12) through (13e) in Section 3-3.4. Table 3-4 summarizes the inputs and outputs for Subroutine FRESNL.

Table 3-4. Input and output variables .r Subroutine FRESNL.

INPUT VARIABLES	
Argument List	
ZLAM	- Wavelength. (μm)
OMEGA	- Angle of incidence (with respect to normal to smooth element of water surface). (radians)
OUTPUT VARIABLE	
Argument List	
RHO	- Fresnel monochromatic reflectance of plane, unpolarized electromagnetic wave incident at angle ω on plane, absorbing surface of water with complex index of refraction N=n-ik obtained from Downing and Williams [DW-75]. (dimensionless)

3-6.5 Subroutine GCRCLE

For three points P_1, P_2, and P_3 on a great circle, Subroutine GCRCLE computes the latitude and longitude of the intermediate point P_2, given the latitudes and longitudes of the end points P_1 and P_3, the central angle α_{13} between the central rays to P_1 and P_3, and the central angle α_{12} between the central rays to P_1 and P_2.

Application of the cosine law for a side of the spherical triangle P_1-N-P_3 in Figure 3-7 gives the relation

$$\cos\left(\frac{\pi}{2}-\theta_3\right) = \cos\alpha_{13}\cos\left(\frac{\pi}{2}-\theta_1\right) + \sin\alpha_{13}\sin\left(\frac{\pi}{2}-\theta_1\right)\cos\lambda$$

or

$$\cos\lambda = \frac{\sin\theta_3 - \cos\alpha_{13}\sin\theta_1}{\sin\alpha_{13}\cos\theta_1} .$$

Similarly, for triangle P_1-N-P_2 in Figure 3-7, we have

$$\cos\left(\frac{\pi}{2}-\theta_2\right) = \cos\alpha_{12}\cos\left(\frac{\pi}{2}-\theta_1\right) + \sin\alpha_{12}\sin\left(\frac{\pi}{2}-\theta_1\right)\cos\lambda$$

or

$$\sin\theta_2 = \cos\alpha_{12}\sin\theta_1 + \sin\alpha_{12}\cos\theta_1\cos\lambda\ .$$

Application of the sine law to the spherical triangle P_1-N-P_2 in Figure 3-7 gives

$$\frac{\sin(\phi_2-\phi_1)}{\sin\alpha_{12}} = \frac{\sin\lambda}{\sin(\frac{\pi}{2}-\theta_2)}$$

or

$$\sin(\phi_2-\phi_1) = \sin\alpha_{12}\sin\lambda/\cos\theta_2 .$$

Thus,

$$\phi_2 = \phi_1 + (\phi_2-\phi_1) \times \mathrm{SIGN}(1.0,\ \phi_3-\phi_1)\ .$$

If $\quad |\phi_3-\phi_1| > \pi,\ \phi_2 = \phi_1 - (\phi_2-\phi_1) \times \mathrm{SIGN}(1.0,\ \phi_3-\phi_1)$.

If $\quad \phi_2 < 0.0, \qquad \phi_2 = \phi_2 + 2\pi$.

If $\quad \phi_2 \geq 2\pi, \qquad \phi_2 = \phi_2 - 2\pi$.

See Table 3-5 for a summary of the inputs and outputs for Subroutine GCRCLE.

Table 3-5. Input and output variables for Subroutine GCRCLE.

INPUT VARIABLES

Argument List

P1LAT, P1LON	-	North latitude and east longitude of Point P_1. (radians)
P3LAT, P3LON	-	North latitude and east longitude of Point P_3. (radians)
ALP13	-	Earth-central angle between rays to Points P_1 and P_3. (radians)
ALP12	-	Earth-central angle between rays to Point P_1 and P_2. (radians)

OUTPUT VARIABLES

Argument list

P2LAT, P2LON	-	North latitude and east longitude of Point P_2. (radians)

SECTION 4

SOLAR RADIATION

4-1 INTRODUCTION

4-1.1 Requirements for the Model

Solar radiation must be modeled because it is a source of sensor illumination, and atmospheric and fireball species excitation, through scattering and/or reflection from the Earth's surface, clouds, aerosols, and dust, either naturally occurring or caused by the fireball.

4-1.2 Model Function

The Solar Radiation Model (23e) consists of a statement of the solar spectral irradiance, at the top of the Earth's atmosphere, in the spectral range from 2 to 5 μm (or 5000 to 2000 cm^{-1}).

4-2 DATA BASE

As a result of extensive work by NASA related to the design of space vehicles, an engineering standard for solar irradiance has been adopted by the American Society of Testing and Materials (ASTM) [Th-74a, Th-76]. We have adopted the tabular data presented by Thekaekara [Th-74a]. Columns 1 and 2 in Table 4-1 present data abstracted from Table I of Th-74a in the spectral range from 2 to 5 μm at 0.1 μm intervals. These data are plotted in Figure 4-1 as the circled points and have been fitted by the following piecewise-continuous power-law expression:

Table 4-1. Solar spectral irradiance (2 to 5 µm).

λ µm	E_λ[a] $\frac{W}{m^2\ \mu m}$	E_λ[b] $\frac{W}{m^2\ \mu m}$	Percent[c] Error	E_λ[d] $\frac{10^{16}\ \text{photon}}{cm^2\ sec\ \mu m}$	E_ν[e] $\frac{10^{13}\ \text{photon}}{cm^2\ sec\ cm^{-1}}$	E_ν[f] $\frac{10^{-7}\ W}{cm^2\ cm^{-1}}$	cm^{-1}
2.0	103	104.62	1.5	10.4	4.15	41.2	5000
2.1	90	90.61	0.7	9.51	4.20	39.7	4762
2.2	79	79.00	0.0	8.75	4.23	38.2	4545
2.3	69	69.30	0.4	7.99	4.23	36.5	4348
2.4	62	61.13	-1.4	7.49	4.31	35.7	4167
2.5	55	54.20	-1.5	6.92	4.33	34.4	4000
2.6	48	48.29	0.6	6.28	4.25	32.4	3846
2.7	43	43.20	0.5	5.84	4.26	31.3	3704
2.8	39	38.81	-0.5	5.50	4.31	30.6	3571
2.9	35	35.00	0.0	5.11	4.30	29.4	3448
3.0	31	29.90	-3.7	4.68	4.21	27.9	3333
3.1	26.0	25.67	-1.3	4.06	3.90	25.0	3226
3.2	22.6	22.15	-2.0	3.64	3.73	23.1	3125
3.3	19.2	19.19	0.0	3.19	3.47	20.9	3030
3.4	16.6	16.71	0.6	2.84	3.28	19.2	2941
3.5	14.6	14.60	0.0	2.57	3.15	17.9	2857
3.6	13.5	13.33	-1.2	2.45	3.17	17.5	2778
3.7	12.3	12.21	-0.7	2.29	3.14	16.8	2703
3.8	11.1	11.21	0.9	2.12	3.07	16.0	2632
3.9	10.3	10.31	0.1	2.02	3.08	15.7	2564
4.0	9.5	9.50	0.0	1.91	3.06	15.2	2550

(continued)

Table 4-1. Solar spectral irradiance (2 to 5 μm) (Cont'd).

λ (μm)	E_λ[a] $\frac{W}{m^2\ \mu m}$	E_λ[b] $\frac{W}{m^2\ \mu m}$	Percent[c] Error	E_λ[d] $\frac{10^{16}\ photon}{cm^2\ sec\ \mu m}$	E_ω[e] $\frac{10^{13}\ photon}{cm^2\ sec\ cm^{-1}}$	E_ω[f] $\frac{10^{-7}\ W}{cm^2\ cm^{-1}}$	ω (cm^{-1})
4.1	8.70	8.58	-1.4	1.80	3.02	14.6	2439
4.2	7.80	7.77	-0.4	1.65	2.91	13.8	2381
4.3	7.10	7.05	-0.7	1.54	2.84	13.1	2326
4.4	6.50	6.42	-1.3	1.44	2.79	12.6	2273
4.5	5.92	5.85	-1.2	1.34	2.72	12.0	2222
4.6	5.35	5.34	-0.1	1.24	2.62	11.3	2174
4.7	4.86	4.89	0.6	1.15	2.54	10.7	2128
4.8	4.47	4.48	0.3	1.08	2.49	10.3	2083
4.9	4.11	4.12	0.2	1.01	2.43	9.87	2041
5.0	3.79	3.79	0.0	0.954	2.38	9.47	2000

[a]From Th-74a, Table I.

[b]Computed from fit function, Equation (1).

[c]Percent error in fit-function values with respect to Column-2 data.

[d]Computed from Equation (4) and Column-2 data.

[e]Computed from Equation (5) and Column-2 data.

[f]Computed from Equation (6) and Column-2 data.

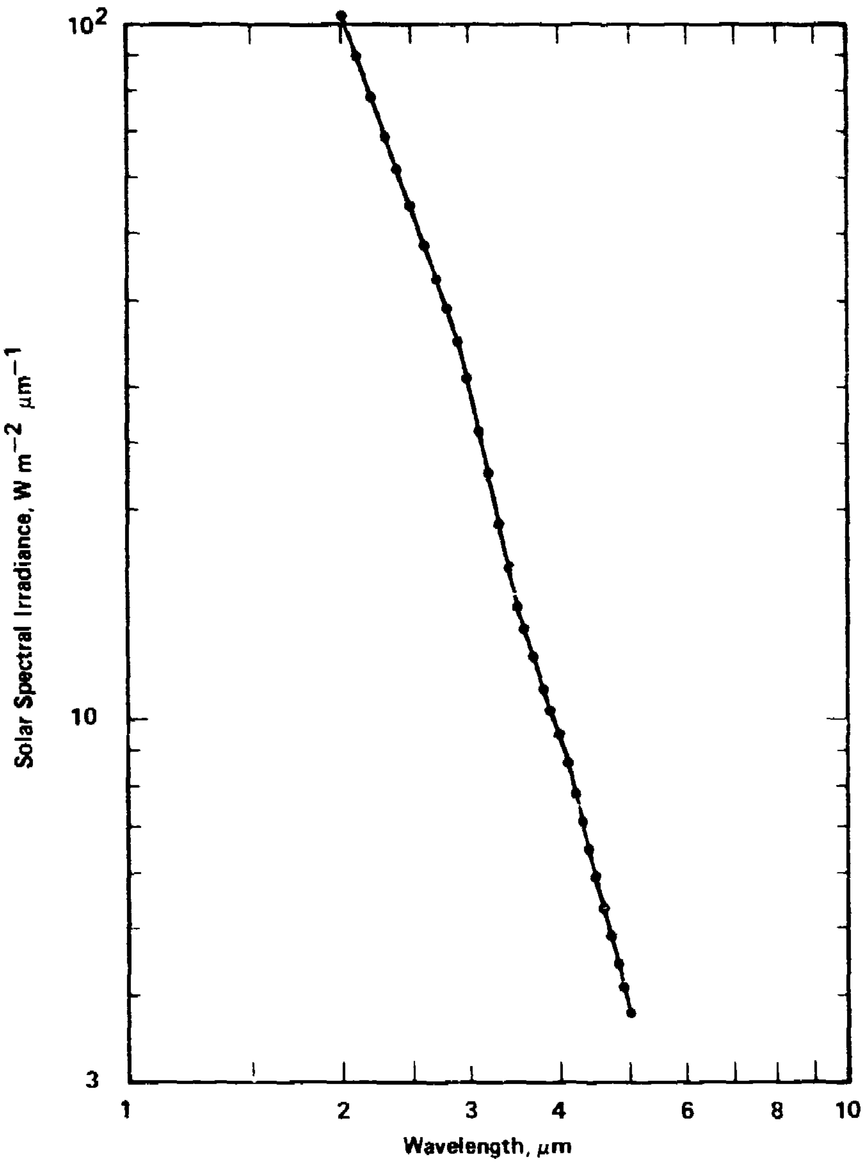


Figure 4–1. Solar spectral irradiance from 2 to 5 μm (units of W m^{-2} μm^{-1}).

$$
E_\lambda(\mathrm{W\ m^{-2}\ \mu m^{-1}}) = \begin{cases} E_{2.2}(\lambda/2.2)^a & 2.0 \le \lambda < 2.9 \quad \text{(1a)} \\ E_{2.9}(\lambda/2.9)^b & 2.9 \le \lambda < 3.5 \quad \text{(1b)} \\ E_{3.5}(\lambda/3.5)^c & 3.5 \le \lambda < 4.0 \quad \text{(1c)} \\ E_{4.0}(\lambda/4.0)^d & 4.0 \le \lambda \le 5.0 \quad \text{(1d)} \end{cases}
$$

where

$$a = \frac{\log E_{2.9} - \log E_{2.2}}{\log 2.9 - \log 2.2} = -\ 2.94693 \tag{2a}$$

$$b = \frac{\log E_{3.5} - \log E_{2.9}}{\log 3.5 - \log 2.9} = -\ 4.64938 \tag{2b}$$

$$c = \frac{\log E_{4.0} - \log E_{3.5}}{\log 4.0 - \log 3.5} = -\ 3.21819 \tag{2c}$$

$$d = \frac{\log E_{5.0} - \log E_{4.0}}{\log 5.0 - \log 4.0} = -\ 4.11809 \tag{2d}$$

$$E_{2.2} = 79 \tag{3a}$$

$$E_{2.9} = 35 \tag{3b}$$

$$E_{3.5} = 14.6 \tag{3c}$$

$$E_{4.0} = 9.5 \tag{3d}$$

$$E_{5.0} = 3.79 \tag{3e}$$

Evaluation of the fit function gives the values and percentage errors in Columns 3 and 4 of Table 4-1, respectively.

By using the conversion relations derived in Section 4-4, we can convert the units of the spectral irradiance from $E_\lambda[W/(m^2\ \mu m)]$ to E_λ[photon/(cm^2 sec μm)] by writing

$$E_\lambda \left|\frac{\text{photon}}{cm^2\ \text{sec}\ \mu m}\right| = E_\lambda \left|\frac{W}{m^2\ \mu m}\right| \times \frac{(10^{-4}/hc)\lambda\ \frac{\text{photon}}{W\ \text{sec}}}{(10^2\ cm/m)^2}$$

or

$$\boxed{E_\lambda \left|\frac{\text{photon}}{cm^2\ \text{sec}\ \mu m}\right| = 5.03404 \times 10^{14}\ \lambda\ E_\lambda \left|\frac{W}{m^2\ \mu m}\right|.} \tag{4}$$

The product hc is expressed in units of J cm and λ in μm. Similarly, we can convert from $E_\lambda[W/(m^2\ \mu m)]$ to E_ω[photon/(cm^2 sec cm^{-1})] by writing

$$E_\omega \left|\frac{\text{photon}}{cm^2\ \text{sec}\ cm^{-1}}\right| = E_\lambda \left|\frac{W}{m^2\ \mu m}\right| \times \frac{(10^{-4}/hc)\ \lambda\ \frac{\text{photon}}{W\ \text{sec}}}{(10^2\ cm/m)^2\ 10^4\ \lambda^{-2}\ cm^{-1}/\mu m}$$

or

$$E_\omega \left|\frac{\text{photon}}{cm^2\ \text{sec}\ cm^{-1}}\right| = 5.03404 \times 10^{10}\ \lambda^3 E_\lambda \left|\frac{W}{m^2\ \mu m}\right|. \tag{5}$$

We can convert from $E_\lambda[W/(m^2\ \mu m)]$ to $E_\omega[W/(cm^2\ cm^{-1})]$ by writing

$$E_\omega \left|\frac{W}{cm^2\ cm^{-1}}\right| = E_\lambda \left|\frac{W}{m^2\ \mu m}\right| \times \frac{1}{(10^2\ cm/m)^2\ 10^4\ \lambda^{-2}\ cm^{-1}/\mu m}$$

or

$$E_{\nu}\left[\frac{W}{cm^2\ cm^{-1}}\right] = 10^{-8}\ \lambda^2\ E_{\lambda}\left[\frac{W}{m^2\ \mu m}\right] . \qquad (6)$$

The quantities E_{λ} [photon/(cm^2 sec μm)], E_{ν} [photon/(cm^2 sec cm^{-1})], and E_{ν} [W/(cm^2 cm^{-1})] are given in Columns 5, 6, and 7 of Table 4-1, respectively, and are plotted in Figures 4-2, 4-3, and 4-4, respectively.

4-3 SUBROUTINE SOLRAD

For Subroutine SOLRAD, see Table 4-2 for a summary of the input and output variables and Figure 4-5 for a flow chart.

Table 4-2. Input and output variables for Subroutine SOLRAD.

INPUT VARIABLES

Argument List

K - Index specifying units for input and output

B - Wavenumber (cm^{-1}) for K=1,2,3,4; Wavelength (μm) for K=5,6,7,8

OUTPUT VARIABLES

Argument List

E - Solar spectral irradiance at the top of the Earth's atmosphere, in units of:

photons cm^{-2} sec^{-1}/cm^{-1}	K = 1,5
photons cm^{-2} sec^{-1} μm^{-1}	K = 2,6
W cm^{-2}/cm^{-1}	K = 3,7
W m^{-2} μm^{-1}	K = 4,8

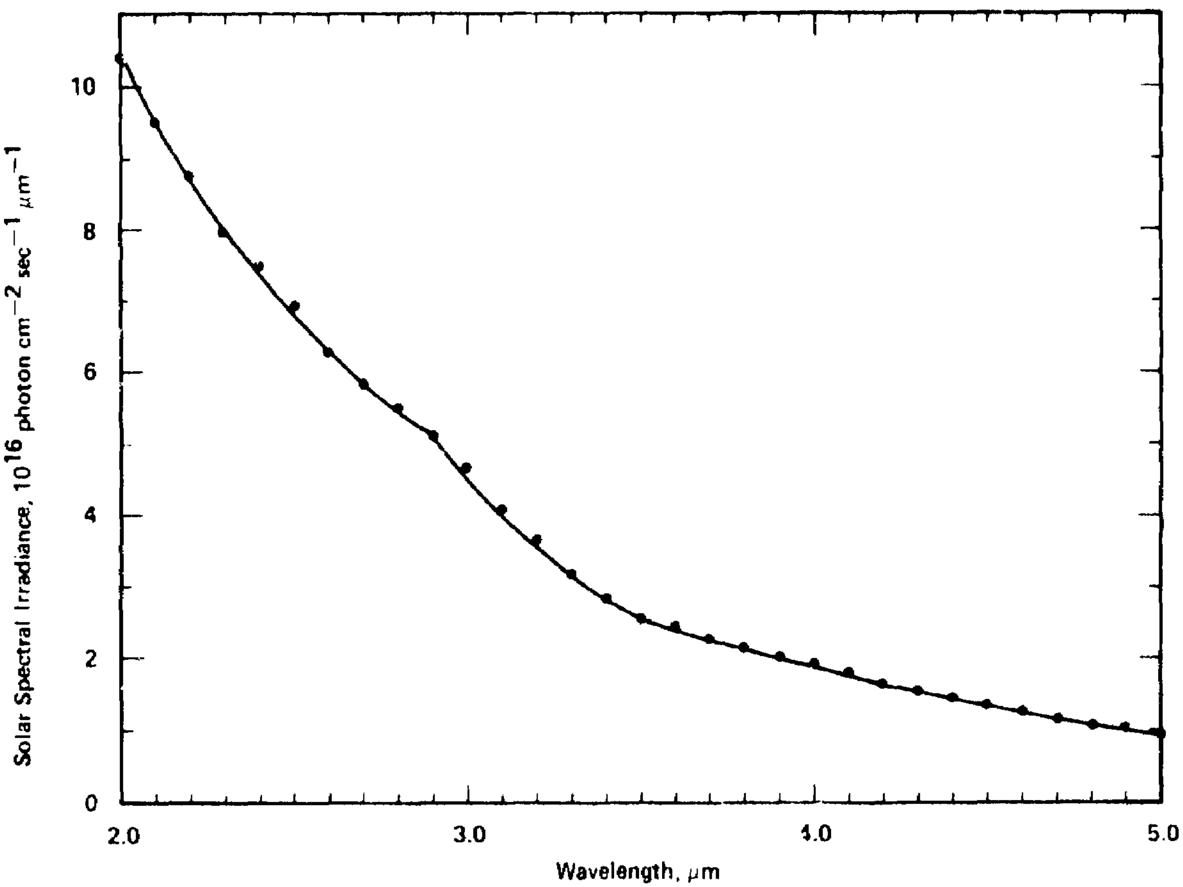


Figure 4-2. Solar spectral irradiance from 2 to 5 μm (units of photon cm^{-2} sec^{-1} μm^{-1}). The circled points correspond to the data in column 2 of Table 4-1 and the solid curve to the fit function.

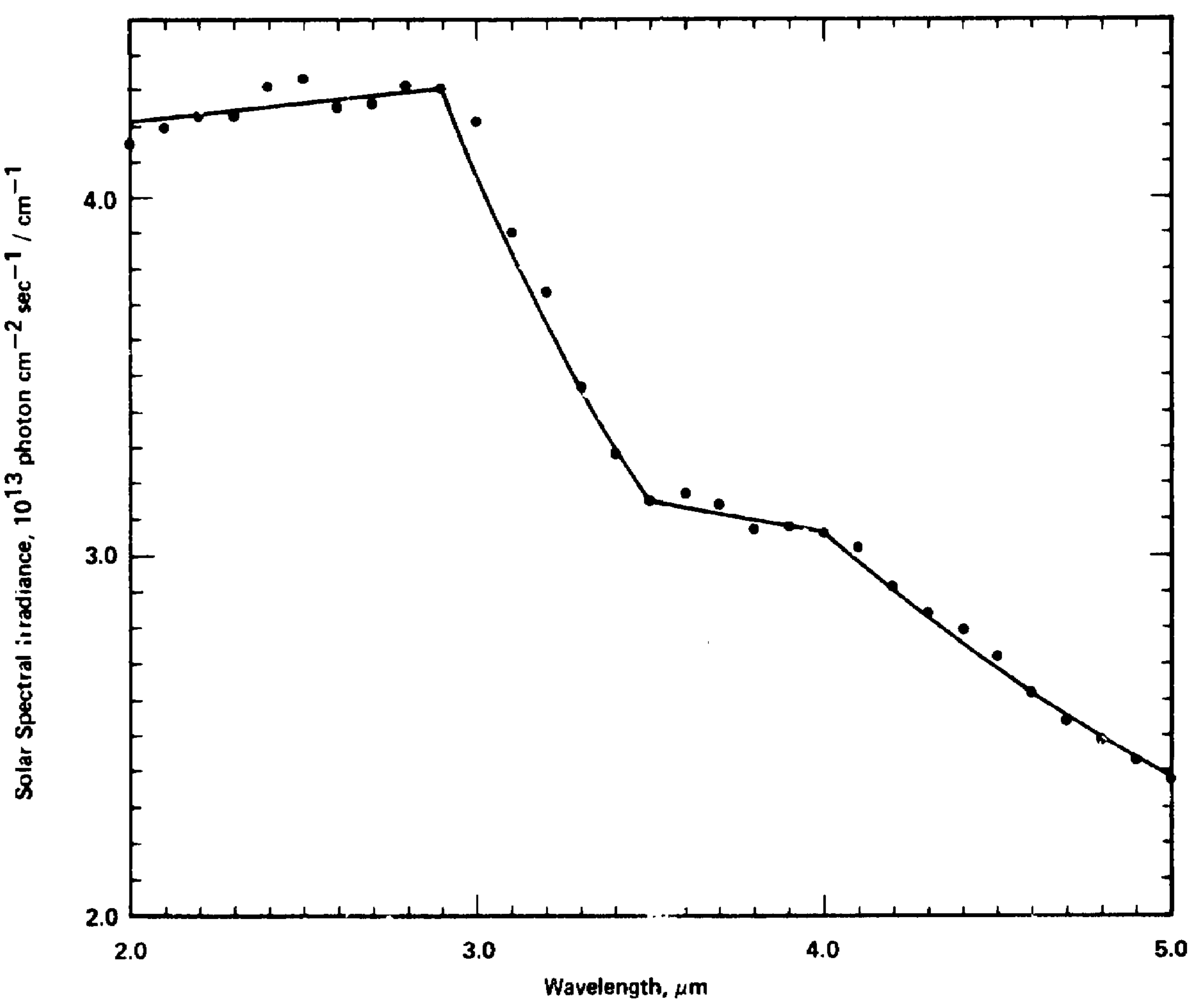


Figure 4–3. Solar spectral irradiance from 2 to 5 μm (units of photon cm^{-2} sec^{-1} / cm^{-1}). The circled points correspond to the data in Column 2 of Table 4–1 and the solid curve to the fit function.

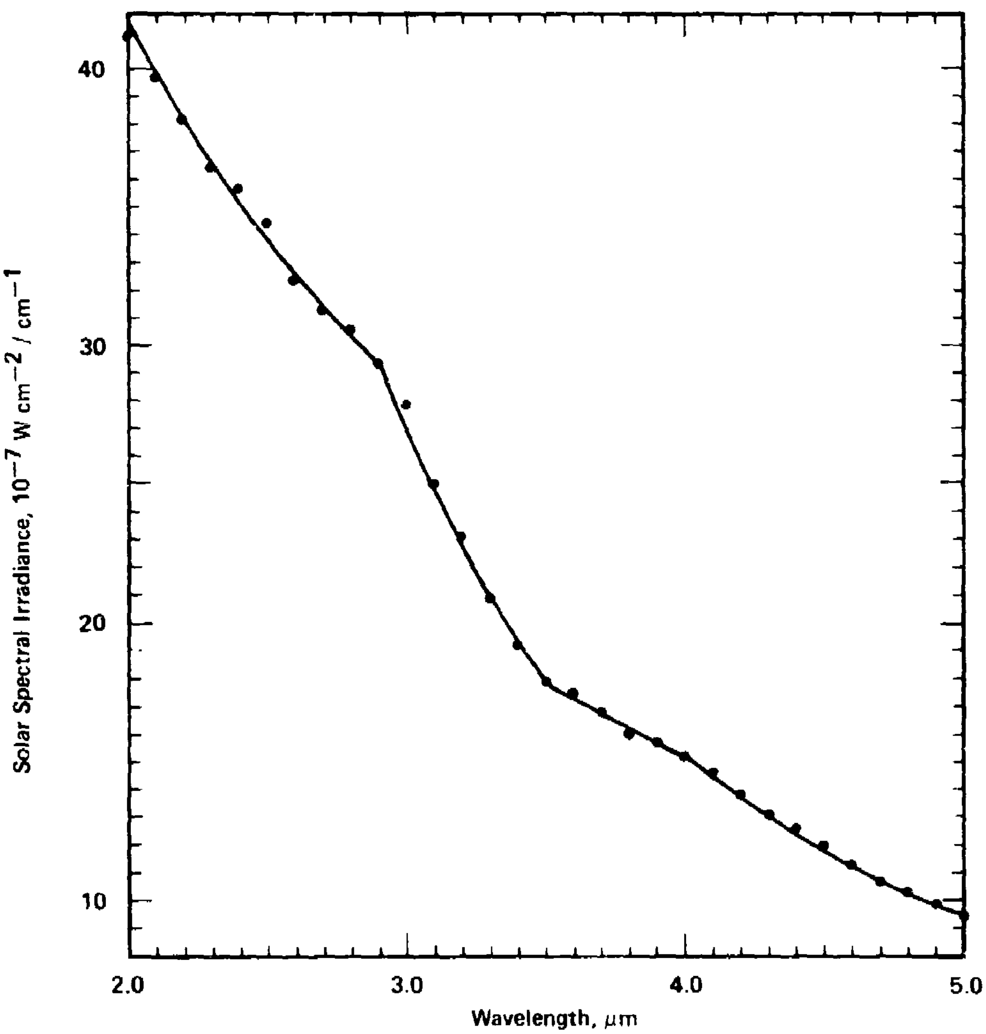


Figure 4–4. Solar spectral irradiance from 2 to 5 μm (units of W cm^{-2} / cm^{-1}). The circled points correspond to the data in column 2 of Table 4–1 and the solid curve to the fit function.

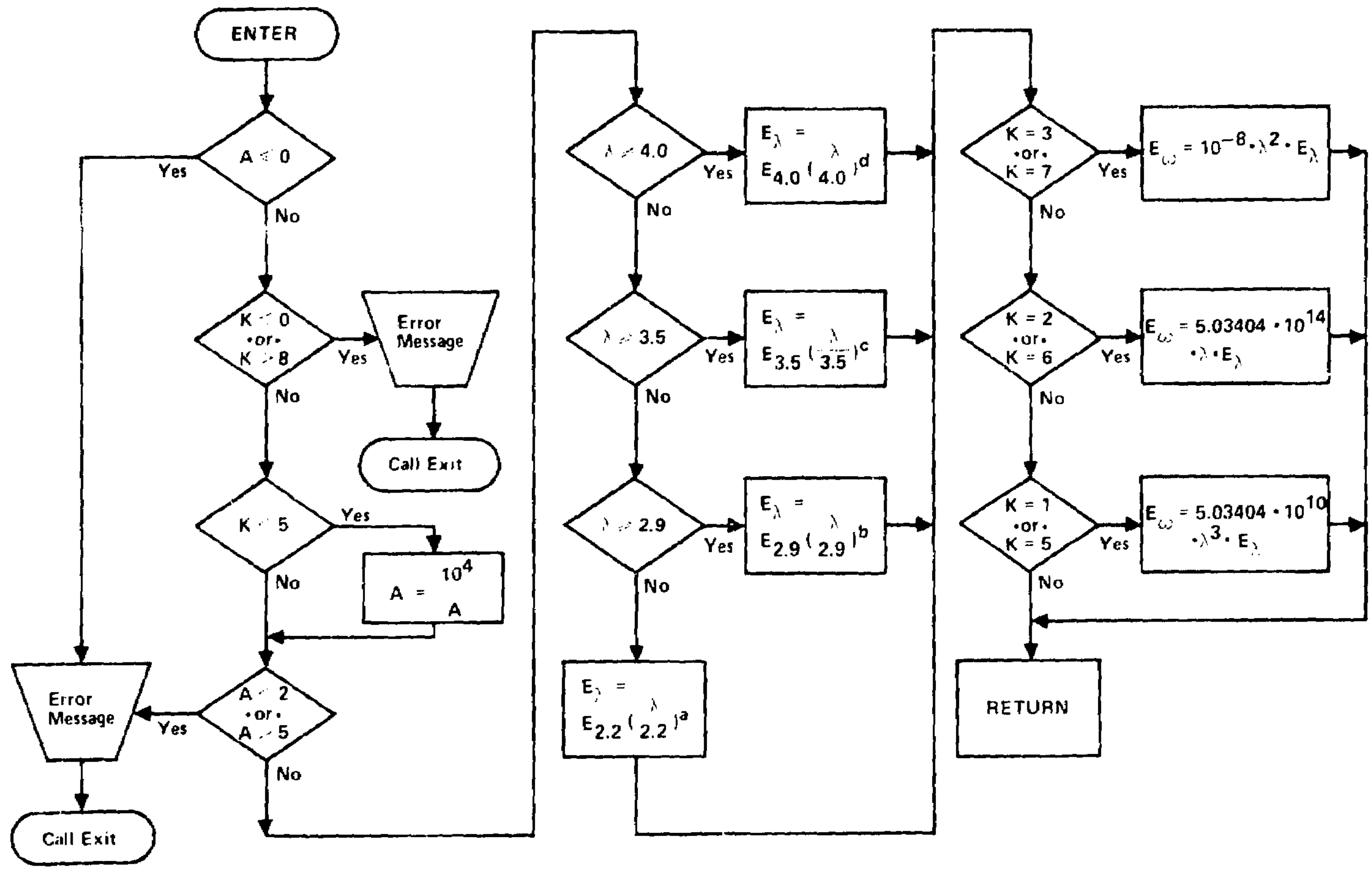


Figure 4–5. Flow chart for Subroutine SOLRAD.

4-4 SOME CONVERSION RELATIONS

Some useful conversion relations may be derived as follows:

1. Energy photon^{-1} = $h\nu = hc/\lambda_{cm} = hc\omega$, W sec

   where hc is expressed in J cm and ω in inverse centimeters. If we use the values of h and c from Cohen and Taylor [CT-73b, Table 33.1 on p. 717], we have

$$hc = \frac{6.626176 \times 10^{-27} \text{ erg sec}}{10^{7} \text{ erg/J}} \times 2.997924 \times 10^{10} \text{ cm/sec}$$

$$\boxed{\begin{aligned} hc &= 1.98648 \times 10^{-23} \text{ J cm} \\ 1/hc &= 5.03404 \times 10^{22} \text{ J}^{-1} \text{ cm}^{-1} \end{aligned}}$$

   Also,

$$\text{Energy photon}^{-1} = 10^{4}\ hc/\lambda, \text{ W sec}$$

   where λ is in micrometers; thus,

$$\boxed{\begin{aligned} 1 \text{ Watt} &= 10^{-4}\ \lambda/hc, \text{ photon sec}^{-1} \\ &= 1/hc\omega, \text{ photon sec}^{-1} \end{aligned}}$$

2. $\lambda = 10^{4}/\omega$

   $|d\lambda/d\omega| = 10^{4}/\omega^{2}$

   micron wavenumber^{-1} = $10^{4}/\omega^{2}$

$$= 10^{-4}\ \lambda^{2}$$

or

$$\boxed{\begin{aligned}\text{wavenumber micron}^{-1} &= 10^{-4}\,\omega^2\\ &= 10^4/\lambda^2\end{aligned}}$$

SECTION 5

EARTH SURFACE RADIANCE

5-1 INTRODUCTION

The Earth Surface Radiance Model (23b) provides (essentially), at the Point P where the optical line-of-sight from the detector (which is fictitious in the NBR Module) at Point V intersects the Earth's surface, the upwelling spectral radiance directed toward the detector. The model provides two components of the radiance: (1) thermal radiation emitted at Point P and (2) source radiation reflected at Point P. In the NBR Module, the only source is the sun. Reflected sky radiance is not included.

Strictly, the surface-reflected source radiation is actually provided in an unattenuated form together with the path parameters (areal density U (cm at STP) and the product UP (atm cm, with P the pressure)) integrated along the incoming path from the source. These parameters are required as input to a computation of the molecular absorption over the total two-leg path. The aerosol transmittance along the incoming path from the source to Point P is also provided.

The principal routine in the Earth Surface Radiance Model is Subroutine SURRAD (surface radiance), which makes a number of calls as shown in Figure 5-1. Subroutine SURRAD is discussed in Section 5-2. Subroutine RINOUT (ray-in-out) computes the geometry for the reflected ray and is discussed in Section 5-3. Subroutine ESURF has been discussed in Section 2-5 and Subroutine SOLRAD in Section 4-3. The rest of the routines used in Model 23b, most of which were obtained from other organizations, are described in Section 5-4.

5-2 SUBROUTINE SURRAD

Table 5-1 summarizes the input and output variables for Subroutine SURRAD.

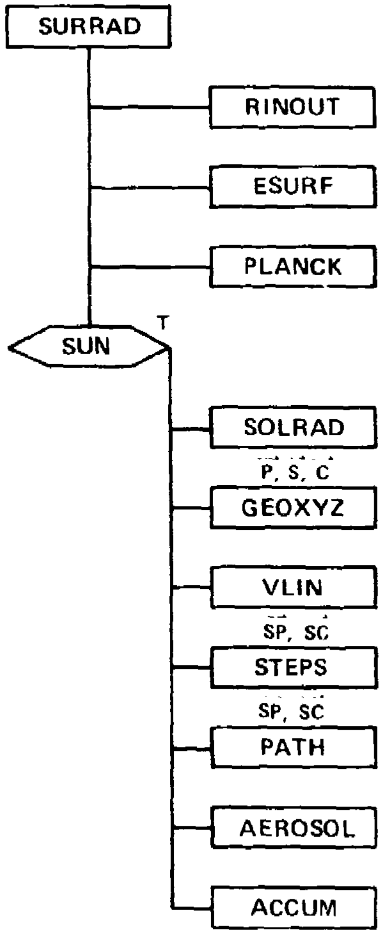


Figure 5--1. Routines called directly from the principal routine (SURRAD) in the Earth Surface Radiance Model. For subsequent calls, see Figure 7--1.

Table 5-1. Input and output variables for Subroutine SURRAD.

INPUT VARIABLES

Argument List

IDETEC - Flag for nature of detector location.

= 1, If detector is at a satellite position (SATLAT, SATLON, SATALT) specified in SATELL Common. (This mode is not used in the NBR Module.)

= 2, If detector is at a position (DETLAT, DETLON, DETALT) specified in TECTOR Common. (This latter option is used when Subroutine SURRAD is called from Subroutine UPWELL in the NBR Module.)

MSM - Index for category of surface material (see Table 2-12 for Subroutine ESURF).

DD - Additional descriptor for selected surface material (see Table 2-12 for Subroutine ESURF).

SPCULR - Logical variable.

= .TRUE., Compute coordinates of specular reflection point on an assumed smooth horizontal water surface.

= .FALSE., Do not compute coordinates of specular reflection point.

(SPCULR appears in SURRAD only to be passed to Subroutine ESURF.)

IUP - Altitude-loop index in Subroutine UPWELL.

JUP - Nadir-loop index in Subroutine UPWELL.

KUP - Azimuth-loop index in Subroutine UPWELL.

LUP - Wavenumber-loop index in Subroutine UPWELL.

(Each of the previous four indices should be set to unity in a call from any routine other than Subroutine UPWELL, which would be a use outside of the NBR Module.)

ZLAM - Wavelength. (μm)

(continued)

Table 5-1. Input and output variables for Subroutine SURRAD (Cont'd).

IFIRES - Flag for inclusion of fireballs as sources.
= 0, No fireball is to be included (always true in NBR Module where Subroutine SURRAD is called from Subroutine UPWELL).

> 0, Fireballs (IFIRES, in number) are to be included with position and radiant intensity specified in FIRBAL Common.

FIRBAL Common (not used in NBR Module)

FBALT(I), FBLAT(I), FBLON(I), FBRINT(I) - Fireball-I altitude, north latitude, east longitude, and spectral radiant intensity. [km, radians, radians, W/(sr cm^{-1}]

POSITN Common

POSALT, POSLAT, POSLON - Altitude, north latitude, and east longitude of Point P at which line-of-sight from (fictitious) detector at Point V intersects Earth's surface. (km, radians, radians)

C12ALT, C12LAT, C12LON - Altitude, north latitude, and east longitude of Point C at which line-of-sight (directed toward Point P from fictitious detector at Point V) intersects the 12-km altitude surface. (km, radians, radians)

SATELL Common (not used in NBR Module)

SATALT, SATLAT, SATLON - Satellite-borne detector altitude, north latitude, and east longitude. (km, radians, radians)

SOLARP Common

SOLLAT, SOLLON - Subsolar-point north latitude and east longitude. (radians)

SOURCE Common

(The variables in this Common are returned from a call to Subroutine RINOUT. In the NBR Module, only the sun is used as a source for Subroutine SURRAD. Fireballs are never used in the NBR Module where Subroutine SURRAD is called from Subroutine UPWELL.)

SRCZEN(1) - Zenith angle of solar ray incoming to Point P. (radians)

(continued)

Table 5-1. Input and output variables for Subroutine SURRAD (Cont'd).

(The following two arrays are not used in the NBR Module; L=1,IFIRES)

SRCZEN(L+1) - Zenith angle of Fireball-L ray incoming to Point P. (radians)

SRCSR(L+1) - Slant range from Fireball-L to Point P. (km)

TECTOR Common

DETALT, DETLAT, DETLON - Altitude, north latitude, and east longitude of fictitious detector at Point V. (km, radians, radians)

UPWELS Common

NWAVE(M) - Number of wavenumbers at which the upwelling spectral radiance is to be computed for broad-band loop-index M≡JBAND.

IDAYV - Index for diurnal condition at Subpoint V'.

= 0, Solar zenith angle > 90 deg.
= 1, Solar zenith angle ≤ 90 deg.

IKM - Index for number of altitudes at which calculations are made when clouds are included (set in Subroutine UPWELL).

UPWELS2 Common

JBAND1 - Same as JBAND in Subroutine UPWELL. Index for list of (broad) wavelength bands.

Data Statement

NSPECS - Number of species in molecular transmittance model.

NTEMP - Number of temperature bins in molecular transmittance model.

OUTPUT VARIABLES

Argument List

RAD(1) - Radiance emitted from surface material at Point P and directed toward detector at Point V. $[W/(cm^2\ sr\ cm^{-1})]$

(continued)

Table 5-1. Input and output variables for Subroutine SURRAD (Cont'd).

RAD(2)	-	Radiance of solar radiation reflected at Point P (with incoming ray unattenuated) and directed toward detector at Point V. [W/(cm^2 sr cm^{-1}]
For L=1,IFIRES (not used in NBR Module)		
RAD(L+2)	-	Radiance of Fireball-L radiation reflected at Point P (with incoming ray unattenuated) and directed toward detector at Point V. [W/(cm^2 sr cm^{-1}]
UPS(I,N,1), UPPS(I,N,1)	-	Path parameters U (areal density) and UP (product of U and pressure P) for temperature-index-I and species-N along incoming solar path to Point P on Earth's surface. Computed only for LUP=1. (cm at STP, atm-cm at STP)
For L=1,IFIRES (not used in NBR Module)		
UPS(I,N,L+1), UPPS(I,N,L+1)	-	Path parameters U and UP along path from Fireball-L to Point P on Earth's surface. Computed only for LUP=1. (cm at STP, atm-cm at STP)
UCS(I,N), UPCS(I,N)	-	Similar to UPS(I,N,1) and UPPS (I,N,1) except Point P is replaced by Point C.
AIRSOL Common		
For LUP=1,NWAVE(JBAND)		
TASP(LUP), TASC(LUP)	-	Aerosol transmittances for incoming solar rays to Point P on Earth's surface and Point C at 12-km altitude. (Depend only on wavelength and assumed single paths.)
For L=1,IFIRES (not used in NBR Module)		
TAFP(L)	-	Aerosol transmittance for incoming ray from Fireball-L to Point P on Earth's surface.
SOLARP Common		
For LL=1,NWAVE(JBAND)		
SOLIRR(LL)	-	Solar spectral irradiance at the top of the atmosphere at wavenumber-index LL. [W/(cm^2 cm^{-1}]

The calculational steps performed in Subroutine SURRAD, as it is employed in the NBR Module, may be described as follows:

A. Preliminaries (done only for spectral index L=1)

1. Call RINOUT to evaluate geometry for solar source, surface point (P), and fictitious detector at Point V. Obtain at Point P:
   a. Detector zenith.
   b. IDAY.
   c. Source zenith (if IDAY=1).
   d. Detector azimuth (if IDAY=1 and MSM >2).

2.1 If IDAYV=1 and IDAY=1, set source zenith into THI and detector azimuth into PSI (if MSM >2).

2.2 If IDAYV=0, set IDAY=0.

3. Set detector zenith into THR.

B. Call ESURF

Obtain surface temperature (TKS), directional emissivity (EPSD), and (if IDAY=1) bidirectional reflectance-distribution function (SFR). If sun and water surface are present and if SPCULR= .TRUE., also get solar specular reflection point on assumed smooth horizontal water surface.

C. Compute surface spectral radiance [RAD(1)] by:

1. Call PLANCK (only for I=J=K=1).
2. Evaluate RAD(1) = EPSD x PLANCK(TKS,W).

D. Compute (unattenuated) surface-reflected solar radiance [RAD(2)] by:

1. Call SOLRAD to get solar irradiance [SOLIRR(L)] at top of the atmosphere (only for I=J=K=1).
2. Evaluate RAD(2) = SFR x SOLIRR(L) x cos (THI).

E. Get path parameters (species areal density U (cm at STP) and the product UP (with P the pressure, atm-cm)) for ray $\overline{SP}$ from sun to

Point P. Assume path parameters are independent of latitude and longitude of P; therefore, do only for I=J=K=L=1. Also get aerosol transmittance from S to P, TASP(L), only for I=J=K=1.

1. Call GEOXYZ (Point P, $\vec{P}$)
2. Call GEOXYZ (Point S, $\vec{S}$)
3. Call STEPS ($\vec{P}$, $\vec{S}$,...)
4. Loop over path segments with calls to PATH, AEROSOL, and ACCUM.
5. Preserve U(I,N,2) and UP(I,N,2) arrays as UPS(I,N,1) and UPPS(I,N,1) arrays.

F. Get path parameters for ray $\overrightarrow{SC}$ from sun to Point C. (This step is included only if natural clouds are included in the calculation. While clouds are not strictly an Earth-surface feature, the treatment of them is analogous to that for Point P and thus is appropriately described here.) Assume path parameters are independent of latitude and longitude of C; therefore, do only for IKM=J=K=L=1. Also get aerosol transmittance from S to C, TASC(L), only for IKM=J=K=1.

1. Call GEOXYZ (Point C, $\vec{C}$).
2. Call STEPS ($\vec{C}$, $\vec{S}$,...).
3. Loop over path segments with calls to PATH, AEROSOL, and ACCUM.
4. Preserve U(I,N,2) and UP(I,N,2) arrays as UCS(I,N) and UPCS(I,N) arrays.

5-3 SUBROUTINE RINOUT

5-3.1 Purpose

Subroutine RINOUT, given the geographic locations of the source (sun and/or fireballs), the detector, and the position P of the intersection of the line-of-sight from the detector to the Earth's surface, computes the zenith angle (and, for fireballs, slant range (but not in NBR Module)) of the source from P and the direction of the ray from P toward the detector in terms of the

zenith angle of the detector and (if the surface is not Lambertian (MAT=1) or water (MAT=2)) the absolute value of the azimuth angle of scatter with respect to the principal plane containing the incoming ray.

See Table 5-2 for a summary of the input and output variables for Subroutine RINOUT and Figure 5-2 for a flow chart.

5-3.2 Derivations

5-3.2.1 Zenith Angle of Sun

Since the Earth's radius subtends a maximum angle of about 4.2×10^{-5} radians at the sun, it is a good approximation to assume that the solar ray to Point P is essentially parallel to the ray to the subsolar point. Thus the great circle arc from Point P to the subsolar point is essentially the solar zenith angle, θ_i, at Point P. This angle θ_i is obtained by applying the cosine law for sides to an oblique spherical triangle, with the result

$$\cos \theta_i = \sin \delta_p \sin \delta_s + \cos \delta_p \cos \delta_s \cos (\phi_s - \phi_p) \tag{1}$$

where δ_p and ϕ_p are the north latitude and east longitude of Point P and δ_s and ϕ_s are the corresponding quantities for the subsolar point. This formula is the same, of course, as that evaluated in Subroutine SOLZEN [Volume 14a-1, HS-79], but we do not use that routine here because it receives its input for Point P from /TIME/, which is inappropriate in the present context.

5-3.2.2 Zenith Angle of Detector

The approximation made in deriving the solar zenith angle is inadequate to use for the zenith angle of a low-altitude detector, as shown in Figure 5-3. Here, the zenith angle is

$$\theta = \alpha_d + \beta \tag{2}$$

Table 5-2. Input and output variables for Subroutine RINOUT.

INPUT VARIABLES

Argument List

MAT	-	Index for category of surface material (see Table 2-12 for Subroutine ESURF).
IFIRE	-	Number of fireballs to be considered as sources (always zero in NBR Module).

FIRBAL Common (not used in NBR Module)

For L=1,IFIRE

FBALT(L), FBLAT(L), FBLON(L), FBRINT(L)	-	Altitude, north latitude, east longitude, and radiant intensity of Fireball-L. (km, radians, radians, W/sec)

POSITN Common

POSALT, POSLAT, POSLON	-	Altitude, north latitude, and east longitude of intersection (Point P) of line-of-sight from detector (at Point V) to Earth's surface. (km, radians, radians)

SOLARP Common

SOLLAT, SOLLON	-	North latitude and east longitude of subsolar point. (radians)

TECTOR Common

DETALT, DETLAT, DETLON	-	Altitude, north latitude, and east longitude of detector at Point V. (km, radians, radians)

OUTPUT VARIABLES

Argument List

IDAY	-	Index for diurnal condition at Point P. = 0, Solar zenith angle > 90 deg. = 1, Solar zenith angle $\leq$ 90 deg.

(continued)

Table 5-2. Input and output variables for Subroutine RINOUT (Cont'd).

SOURCE Common		
SRCZEN(1)	-	Zenith angle of solar ray incoming to Point P on Earth's surface. (radians)
For L=1,IFIRE (not used in NBR Module)		
SRCZEN(L+1), SRCSR(L+1)	-	Zenith angle and slant range of Fireball-L ray incoming to Point P on Earth's surface. (radians, km)
TECTOR Common		
DETZEN	-	Zenith angle of ray reflected at Point P on Earth's surface toward the detector at Point V. (radians)
DETAZI(1)	-	Absolute value of azimuth angle of reflected ray, measured from principal plane determined by vertical plane through incoming solar ray. (radians)
For L=1,IFIRE (not used in NBR Module)		
DETAZI(L+1)	-	Absolute value of azimuth angle of reflected ray, measured from principal plane determined by vertical plane through incoming ray from Fireball-L. (radians)

where the Earth-central angle α_d is obtained from a call to Subroutine CANGLE (see Table 3-3 for Subroutine CANGLE). Thus we need β.

With

R_e = Earth's radius
h_p = Altitude of Point P
h_d = Altitude of Point V,

let

$$b = R_e + h_p \tag{3a}$$
$$c = R_e + h_d \; . \tag{3b}$$

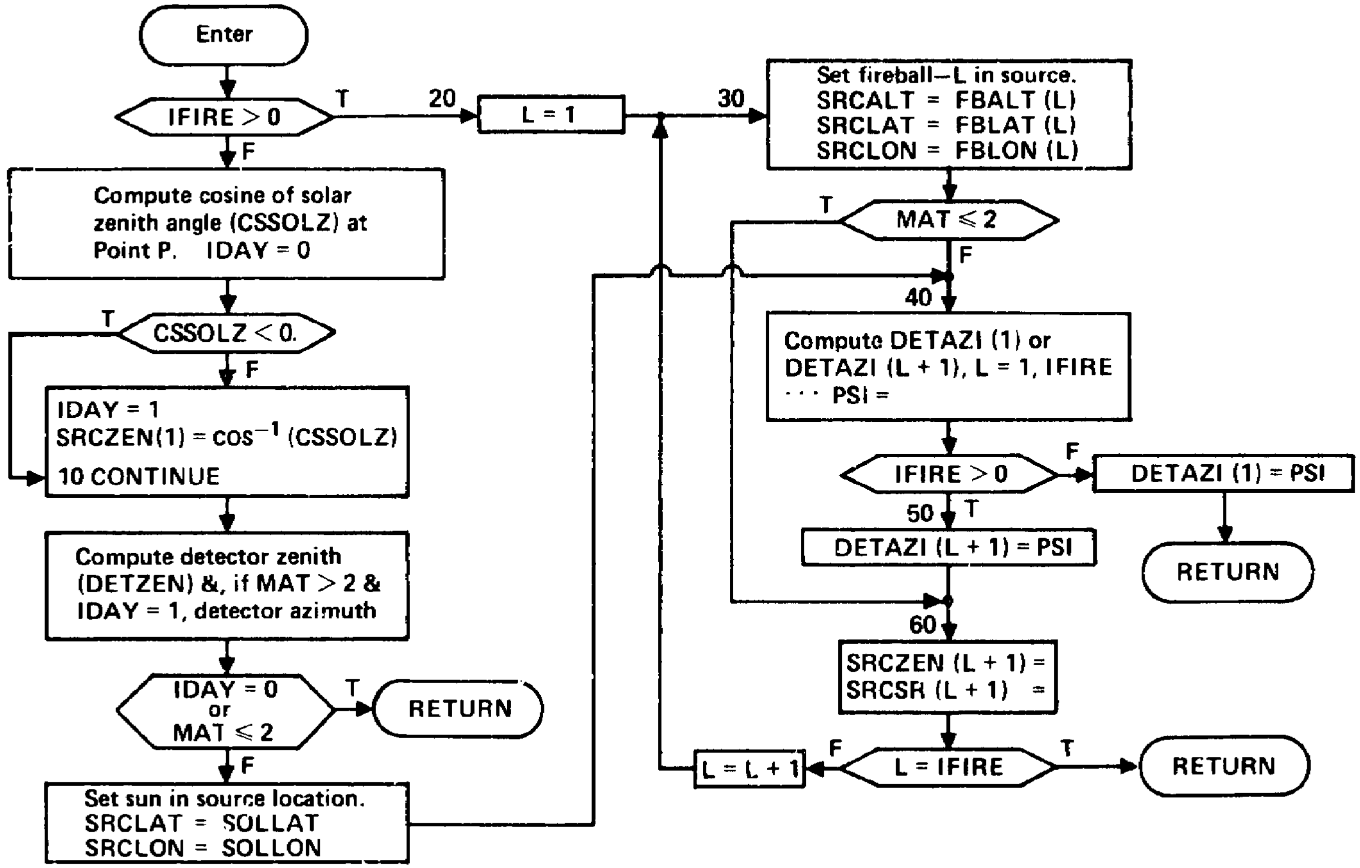


Figure 5–2. Flow chart for Subroutine RINOUT. For completeness, diagram includes calculation for fireball as source, a condition outside the NBR Module.

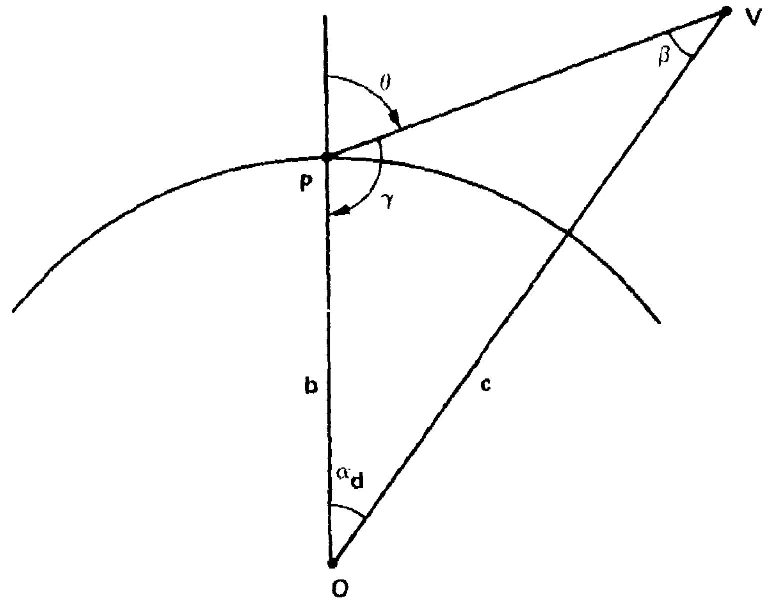


Figure 5–3. Geometry for detector's zenith angle at Point P.

From the law of tangents for a plane triangle, we have

$$\frac{\tan \frac{1}{2}(\gamma+\beta)}{\tan \frac{1}{2}(\gamma-\beta)} = \frac{c+b}{c-b} \tag{4}$$

which, with the use of

$$\gamma + \beta = \pi - \alpha \tag{5}$$

and

$$\varepsilon_d \equiv b/c = (R_e + h_p)/(R_e + h_d), \tag{6}$$

becomes

$$\tan \frac{1}{2} (\gamma-\beta) = \frac{1-\epsilon_d}{1+\epsilon_d} \tan \frac{1}{2} (\pi-\alpha) \tag{7a}$$

or

$$\gamma-\beta = 2 \tan^{-1} \left[\frac{1-\epsilon_d}{1+\epsilon_d} \frac{1}{\tan(\alpha/2)}\right] \equiv C_d \ . \tag{7b}$$

By subtracting Equation (7b) from Equation (5), we have the needed β,

$$\beta = (\pi-\alpha-C_d)/2 \ , \tag{8}$$

to use in Equation (2) for the detector's zenith angle at Point P.

5-3.2.3 Azimuth Angle of Reflected Ray

We want to compute the azimuth angle ψ shown in Figure 5-4. For simplicity in the formulas, we drop the primes from the subpoints V' and S'. Our derivation (which may not be the simplest) requires solving, in turn, triangles P-N-S, Q-N-S, P-Q-N, and P-V-Q. The numbers on the various sides and angles indicate the sequence of solution.

A. For later use, note that NP and NS are known, since

$$NP = \theta_p \tag{9a}$$
$$NS = \theta_s . \tag{9b}$$

Define

$$PNS_t = |\phi_s-\phi_p| \tag{10a}$$

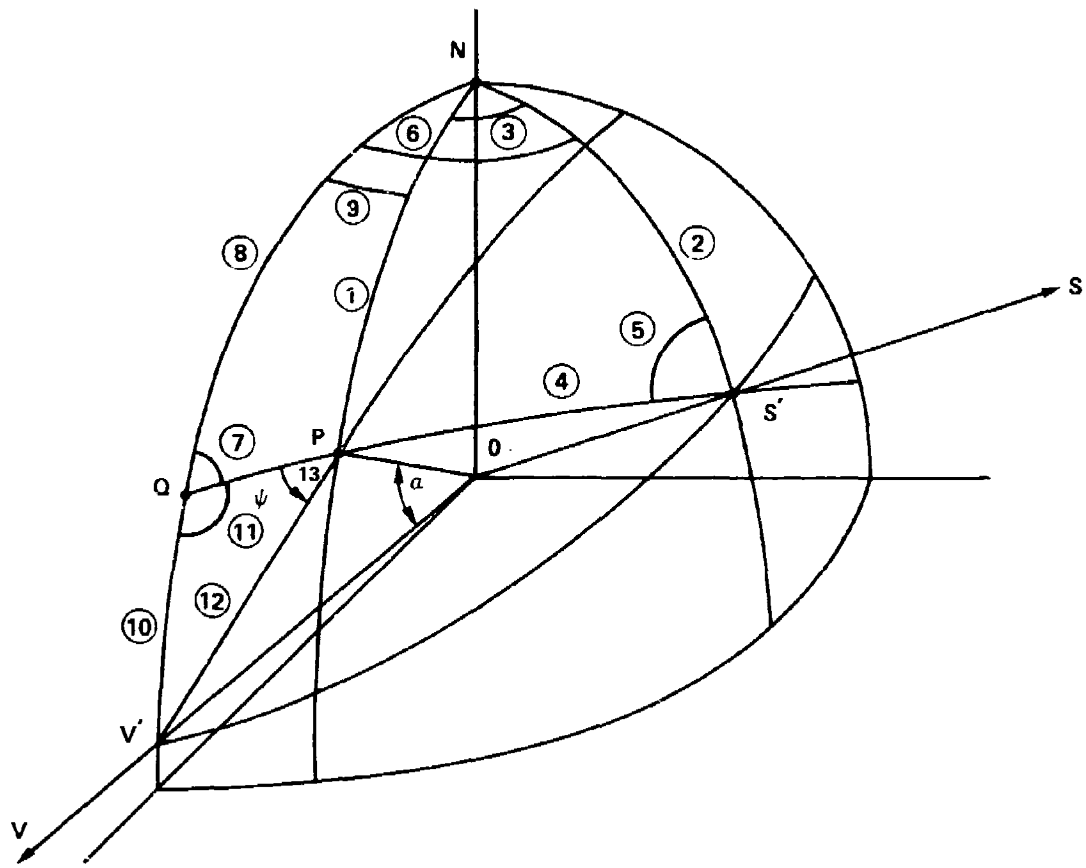


Figure 5–4. Geometry for azimuth angle of reflected ray.

$$QNS_t = |\phi_s - \phi_d| \tag{10b}$$

$$QNP_t = |\phi_p - \phi_d| \; . \tag{10c}$$

B. For triangle P-N-S,

$$PNS = \begin{cases} PNS_t & \text{if } PNS_t < \pi \\ 2\pi - PNS_t & \text{if } PNS_t \geq \pi \end{cases} \tag{11}$$

$$PS = \text{CANGLE}(\theta_p, \phi_p, \theta_s, \phi_s) \tag{12}$$

where CANGLE is the function routine described in Section 3-6.2 From the law of sines,

$$\sin QSN \equiv \sin PSN = \sin NP \sin PNS/\sin PS \tag{13a}$$

$$QSN = \sin^{-1} (\sin QSN). \tag{13b}$$

To determine the proper quadrant for QSN, we consider the consequence of PSN equaling 90°; i.e., by applying the law of cosines for sides to triangle P-S-N, we have

$$\cos NP = \cos PS \cos NS + \sin PS \sin NS \cos QSN \tag{14a}$$

$$\cos NP_R = \cos PS \cos NS. \tag{14b}$$

If $NP > NP_R$, then $QSN > 90°$; i.e., if $\cos NP < \cos NP_R$, then $QSN > 90°$. Thus,

$$QSN = \begin{cases} QSN_P & \text{if } \cos NP \geq \cos NP_R \\ \pi - QSN_P & \text{if } \cos NP < \cos NP_R \end{cases} \tag{15}$$

where the subscript P denotes the principal value of $\sin^{-1}$, as returned by the computer.

C. For triangle Q-N-S,

$$QNS = \begin{cases} QNS_t & \text{if } QNS_t < \pi \\ 2\pi - QNS_t & \text{if } QNS_t \geq \pi . \end{cases} \tag{16}$$

By applying the law of cosines for angles to triangle Q-N-S, we have

$$SQN = \cos^{-1} (\cos QNS \cos QSN + \sin QNS \sin QSN \cos NS) . \tag{17}$$

By applying the law of sines to triangle Q-N-S, we have

$$QN = \sin^{-1} (\sin QSN \sin NS/\sin SQN). \tag{18}$$

To determine the proper quadrant for QN, we consider the consequence of QN equaling 90°; i.e., by applying the law of cosines for angles to triangle Q-N-S, we have

$$\cos QSN = -\cos SQN \cos QNS + \sin SQN \sin QNS \cos QN. \tag{19a}$$

For QN = 90°, we have

$$\cos QSN_R = - \cos SQN \cos QNS. \tag{19b}$$

Now, $SQN \leq \pi$; therefore, $\sin SQN \geq 0$. For daylight conditions at the detector, $QNS \leq \pi/2$; therefore, $\sin QNS \geq 0$. Thus, the second term in (19a) is always positive for QN < 90°. Thus

$$QN = \begin{cases} QN_p & \text{if } \cos QSN \geq \cos QSN_R \\ \pi - QN_p & \text{if } \cos QSN < \cos QSN_R . \end{cases} \tag{20}$$

D. For triangle P-Q-N,

$$QNP = \begin{cases} QNP_t & \text{if } QNP_t < \pi \\ 2\pi - QNP_t & \text{if } QNP_t \geq \pi \end{cases} \quad (21)$$

By applying the law of sines, we have

$$\sin QP = \sin QNP \sin NP/\sin SQN \quad (22a)$$

or

$$\cos QP = (1-\sin^2 QP)^{1/2} , \quad (22b)$$

a quantity we will need later.

E. For triangle P-A-Q, by applying the law of sines, we have

$$\psi = \sin^{-1} (\sin VQ \sin VQP/\sin VP) \quad (23)$$

where VQ is evaluated by noting, for the arc V-Q-N, that

$$VQ = \frac{\pi}{2} - (\theta_d + QN) \quad (24a)$$

$$\sin VQ = \cos (\theta_d + QN) ; \quad (24b)$$

where VQP is evaluated by noting that

$$VQP = \pi - SQN \quad (25a)$$

$$\sin VQP = \sin SQN ; \quad (25b)$$

where VP is evaluated by noting that

$$VP = \alpha_d = \text{CANGLE}(\theta_d, \phi_d, \theta_p, \phi_p). \tag{26}$$

Thus,

$$\psi = \sin^{-1} [\cos(\theta_d + QN) \sin SQN/\sin \alpha_d]. \tag{27}$$

To determine the proper quadrant for ψ, we consider the consequence of ψ equaling 90°; i.e., by applying the law of cosines for sides to triangle P-V-Q, we have

$$\cos VQ = \cos VP \cos QP + \sin VP \sin QP \cos \psi. \tag{28a}$$

For $\psi = 90°$,

$$\cos VQ_R = \cos VP \cos QP \tag{28b}$$
$$= \cos \alpha_d \cos QP. \tag{28c}$$

Thus,

$$\psi = \begin{cases} \psi_p & \text{if } \cos VQ \geq \cos VQ_R \\ \pi - \psi_p & \text{if } \cos VQ < \cos VQ_R. \end{cases} \tag{29}$$

5-4 OTHER ROUTINES IN EARTH SURFACE RADIANCE MODEL

5-4.1 SAI Routines (ESURF, SOLRAD, GEOXYZ)

Among the routines shown in Figure 5-1 to be directly called from Subroutine SURRAD, those (besides RINOUT) that have been prepared by SAI are ESURF (discussed in Section 2-5 and its related water-surface routines in Section 3-6), SOLRAD (discussed in Section 4-3), and GEOXYZ.

Subroutine GEOXYZ converts the geographic coordinates of a point (P) to Earth-centered Cartesian coordinates. Reference to Figure 5-5 aids one in writing the following equations.

$$RP = RE + PH \tag{30}$$

$$RPEQ = RP \times \cos PLAT \tag{31}$$

$$RPX = RPEQ \times \cos PLON \tag{32}$$

$$RPY = RPEQ \times \sin PLON \tag{33}$$

$$RPZ = RP \times \sin PLAT. \tag{34}$$

The input and output variables are summarized in Table 5-3.

5-4.2 Visidyne, Inc. Routine (AEROSOL)

Subroutine AEROSOL, prepared by C.H. Humphrey et al. [Volume 25], computes attenuation coefficients for scattering and absorption (and, though not used in the NBR Module, the asymmetry factor (average cosine of the scattering angle)) due to atmospheric aerosols, given the altitude and wavelength. Table 5-4 summarizes the inputs and outputs for Subroutine AEROSOL.

5-4.3 G.E. Tempo Routines (ACCUM, DOT, FRAC, PATH, PLANCK, SEGMENT, STEP, STEPS, SUBVEC, UNITV, VLIN, XMIT)

Among the routines shown in Figure 5-1 to be directly called from Subroutine SURRAD, those that have been prepared by G.E. Tempo are Function PLANCK, Subroutine VLIN, Subroutine STEPS (and its auxiliary routines SUBVEC, VLIN, DOT, UNITV, STEP, and FRAC), Subroutine PATH (and its auxiliary routines XMIT and SEGMENT), and Subroutine ACCUM. A brief description of the purpose of each of these routines is included in Table 7-3a which summarizes all the routines in the NBR Module. For the longer and more important routines we have summarized their inputs and output: Subroutine PATH (Table 5-5), Function PLANCK (Table 5-6), Subroutine SEGMENT (Table 5-7), Subroutine STEP (Table 5-8), and Subroutine STEPS (Table 5-9). Briefer statements - but in some instances, flow charts - pertaining to these routines have been given by Ewing et al. in Volume 31 (PATH, p. 62; PLANCK, p. 63; SEGMENT, p. 66 with flow chart on p. 67; STEP, p. 68, with flow chart on p. 69; STEPS, p. 70).

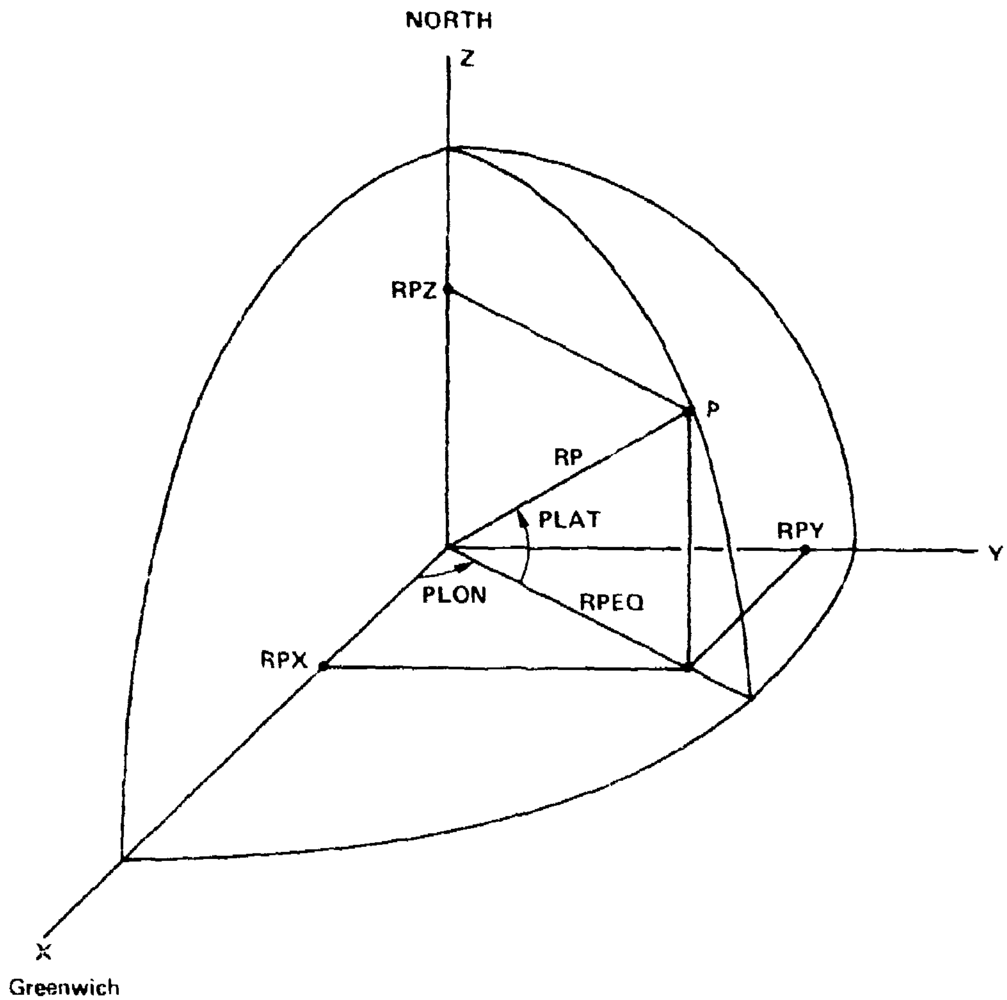


Figure 5–5. Geometry for conversion of geographic coordinates to Earth-centered Cartesian coordinates.

Table 5-3. Input and output variables for Subroutine GEOXYZ.

INPUT VARIABLES		
Argument List		
PH, PLAT, PLON	-	Altitude, north latitude, and east longitude of Point P. (km, radians, radians)
OUTPUT VARIABLES		
Argument List		
RPX, RPY, RPZ	-	Earth-centered Cartesian coordinates X, Y, and Z of Point P. (km)

Table 5-4. Input and output variables for Subroutine AEROSOL.

INPUT VARIABLES

Argument List

HCM	-	Altitude above sea level. (cm)
LAMDA	-	Wavelength. (μm)

AEROK Common

KVIS - Visibility range parameter (VR) for $0 \leq HCM \leq 9 \times 10^5$ cm.

= 1, VR = 50 km
= 2, VR = 23 km
= 3, VR = 10 km
= 4, VR = 5 km
= 5, VR = 2 km.

KTYPE - Terrain parameter for $0 \leq HCM \leq 2 \times 10^5$ cm.

= 1, Terrain is rural
= 2, Terrain is urban
= 3, Terrain is maritime.

(continued)

Table 5-4. Input and output variables for Subroutine AEROSOL (Cont'd).

OUTPUT VARIABLES

Argument List

XKSCT, XKABS	-	Scattering and absorption coefficients. (cm^{-1})
GBAR	-	Asymmetry factor (average cosine of the scattering angle).

Table 5-5. Input and output variables for Subroutine PATH.

INPUT VARIABLES

Argument List

FIRST	-	Logical variable serving as initialization switch. = .TRUE., For first call (i.e., corresponding to path from $\vec{RX}$ to $\vec{RY}$ in Subroutine TRNSCO). = .FALSE., For subsequent calls (i.e., corresponding to path from $\vec{RY}$ to $\vec{RZ}$ in Subroutine TRNSCO).
ISHELL(1), ISHELL(2)	-	INDX(I) and INDX(I+1) in calls from Subroutines TRNSCO and SURRAD.
DS	-	DS(I+1) in calls from Subroutines TRNSCO and SURRAD. Note: It is always true that DS(1) = 0.0 and DS(NC+1) = -1.0, where NC is the number of path segments plus one. Subroutine ATMRAD will not be called from Subroutine TRNSCO with I=NC.
XFRACS(1), XFRACS(2)	-	XFRACS(I) and XFRACS(I+1) in calls from Subroutine TRNSCO and SURRAD. Notes: (1) Do not confuse this array XFRACS (dimensioned 2) with the array XFRACS (dimensioned 100) in Subroutines STEP, STEPS, and TRNSCO. (2) For meaning of XFRACS(I), see Table 6-9 for Subroutine ATMRAD.

(continued)

Table 5-5. Input and output variables for Subroutine PATH (Cont'd).

XYZCOM Common

NS	-	Number of altitude boundaries set in Subroutine SHELLS.

For J=1,NS; N=1,10

TS(J), PS(J), XNSPEC(J,N)	-	Temperature, pressure, and species-N density at altitude boundary J. (deg K, atm, 1/cm^3)

OUTPUT VARIABLES

XYZCOM Common

For I=1,2 (adequate for ambient atmosphere); N=1,10

U(I,N,2), UP(I,N,2)	-	Cumulative value of path parameters U (species-N areal density) and UP (product of U and pressure P) for temperature-index I and species-N at end of line segment DS(J+1). (cm at STP, atm-cm at STP)

Table 5-6. Input and output variables for Function PLANCK.

INPUT VARIABLES

Argument List

T	-	Temperature. (deg K)
W	-	Wavenumber. (1/cm)

Data Statements

C	-	Velocity of light. (cm/sec)
H	-	Planck's constant. (J sec)
CHK	-	C x H/K, where K is Boltzmann's constant. (cm deg-K)

OUTPUT VARIABLES

Function

PLANCK	-	Spectral radiance. [W/(cm^2 sr cm^{-1})]

Table 5-7. Input and output variables for Subroutine SEGMENT.

INPUT VARIABLES

Argument List

NSPEC - Number of species (10) in the molecular transmittance model. These species are identified by comments in Table 7-9 for Subroutine SHELLS.

X1 - Distance along line segment; set as 0.0 in call from Subroutine PATH.

For N = 1,NSPEC

NS1(N), P1, T1 - Array of species concentrations, pressure, and temperature at start of line segment; set in call from PATH as XNS1(10), PSL1, and TSL1. ($1/cm^3$, atm, deg K)

X2 - Length of line segment; set as DS in call from Subroutine PATH. (cm)

NS2(N), P2, T2 - Array of species concentations, pressure, and temperature at end of line segment; set in call from Subroutine PATH as XNS2(10), PSL2, and TSL2. ($1/cm^3$, atm, deg K)

XY Common

For I = 1,10

TT(I) - Temperature array used for band-model parameters. (deg K)

OUTPUT VARIABLES

Argument List

For I=1,10; N=1,10

DU(I,N), DUP(I,N) - Incremental path integrals U (areal density) and UP (product of U and pressure P) for path segment DS, temperature-I, and species-N. (cm at STP, atm-cm at STP)

Table 5-8. Input and output variables for Subroutine STEP.

INPUT VARIABLES

Argument List

$\vec{RX}$ - Location vector to one end of transmission path, typically but not necessarily at the detector. (cm)

$\overrightarrow{SHAT}$ - Unit vector along the transmission path from $\vec{RY}$ to $\vec{RX}$. (cm)

DIST - Magnitude of distance along transmission path from $\vec{RY}$ to $\vec{RX}$. (cm)

NC - Initialization value. Normally set to 0 and leads to DS(1) being set to 0.0.

XYZCOM Common

NS - Number of shell boundaries in atmospheric transmission model.

OUTPUT VARIABLES

Argument List

NC - Number of path segments plus one on the transmission path from $\vec{RY}$ to $\vec{RX}$, or equivalently, the number of end points.

For I=1,NC

DS(I+1) - Length of line segment I along transmission path. (cm) Note: It is always true that DS(1) = 0.0 and DS(NC+1) = -1.0. (There are two more values of DS than there are segments.)

XFRACS(I) - The weight associated with the Ith end point appropriate for finding at that point the linearly-interpolated value of parameters - such as temperature and pressure (or even altitude) - which are specified at the two shell boundaries adjacent to the Ith end point.

Note: For verification of this interpretation, see the usage of XFRAC(1) and XFRAC(2) in Subroutine ATMRAD for obtaining altitude and temperature at front and back of cell DS. The same conclusion may be drawn from the usage of XFRACS(1) and XFRACS(2) in Subroutine PATH.

(continued)

Table 5-8. Input and output variables for Subroutine STEP (Cont'd).

It is useful to consider a hypothetical example with HSHELL(I) = 0.0, 1.0, 2.0, 3.0 for I=1,2,3,4 and 45-degree path from altitude 1.9 to 2.9 km. Then, NC=3 and we have the following values for the arrays:

I	DS(I)	XFRACS(I)	INDX(I)
1	0.0	0.1	2
2	0.1414	1.0	3
3	1.2728	0.9	4
4	-1.0	Not defined	0

INDX(I) - Index of shell boundary at or just before the start of the line segment I. INDX(NC) will be the index of the shell boundary just after the last endpoint.
Note: INDX(NC+1) = 0.

Table 5-9. Input and output variables for Subroutine STEPS.

INPUT VARIABLES

Argument List

$\vec{RX}$ - Location vector to one end of transmission path, typically but not necessarily at the detector. (cm)

$\vec{RY}$ - Location vector to one end of transmission path, typically but not necessarily at the scattering or source point. (cm)

NC - Initialization value. Normally set to 0 and leads to DS(1) being set to 0.0 in Subroutine STEP.

OUTPUT VARIABLES

Internal Use (for call to Subroutine STEP)

$\overrightarrow{SHAT}$ - Unit vector along the transmission path from $\vec{RY}$ to $\vec{RX}$. (cm)

DIST - Magnitude of distance along transmission path from $\vec{RY}$ to $\vec{RX}$. (cm)

(continued)

Table 5-9. Input and output variables for Subroutine STEPS (Cont'd).

Argument List The following quantities are obtained by a call to Subroutine STEP (see Table 5-8 for Subroutine STEP): NC, DS, XFRACS, and INDX.

SECTION 6

UPWELLING NATURAL RADIATION

6-1 INTRODUCTION

6-1.1 Requirement

The Upwelling Natural Radiation Model (23c) is required to provide the mean upwelling spectral radiance at a viewing Point V at any altitude in the atmosphere, with account of the effects of solar radiation reflected from the Earth and clouds, emitted radiation from the Earth, atmosphere, and clouds, and attenuation by atmospheric aerosols.

6-1.2 Approach

The mean upwelling spectral radiance is evaluated, in principle, by averaging the upwelling spectral radiance over the solid angle (Ω_T) defined by the cone with vertex at Point V and tangent to the Earth's surface. In practice, we average the set of spectral radiances received by a (fictitious) detector viewing, from Point V, a set of characteristic Points P on the Earth's surface and within Ω_T. (For now, we ignore clouds.) The selection of the Points P is done by first dividing Ω_T into a number of regions ($N_N \leq 10$) bounded by common-vertex cones, each region with solid angle $\Delta\Omega = \Omega_T/N_N$. For each region we determine an angle β, measured from the nadir, which defines a cone that bisects $\Delta\Omega$. (For brevity, we will hereafter let the phrase 'nadir angle' mean an angle measured from the nadir, just as 'zenith angle' means an angle measured from the zenith.) For daytime, we assume symmetry about the vertical (or principal) plane passing through Point V and the sun. The region on one side of the principal plane is divided into a number of sectors, each with angle π/N_A ($N_A \leq 6$ for day; $N_A = 1$ for night since complete azimuthal symmetry then obtains). The intersections between the bisecting cones and the planes bisecting the sectors are a set of $N_N \times N_A$ lines which intersect the Earth's surface at a set of points we call Points P. We assume the upwelling

radiance directed from a Point P to Point V is representative of that from the entire facet associated with the Point P.

In the absence of clouds, we model the upwelling radiance directed along a Path $\overrightarrow{PV}$ (i.e., from Point P to Point V) by including contributions from (1) air emission between Points V and P, (2) surface emission at Point P, and (3) solar radiation reflected from the surface at Point P. (We do not include air emission reflected at Point P.) Let us denote such radiance as UPRAD(I,J,K,L), with I,J,K, and L being indices for altitude, nadir angle, azimuth angle, and wavenumber, respectively.

To obtain a mean value for the upwelling radiance, we first average UPRAD(I,J,K,L) over azimuth angles for a constant nadir angle to get UPRADA(I,J,L) and then average UPRADA(I,J,L) over nadir angles to get UPRADN(I,L). Very recently this last array has been extended to UPRADN(I,L,JBAND) to provide for a broad-band spectral index JBAND.

The inclusion of natural clouds complicates the modeling. No attempt is made to include the deterministic cloud submodel. The statistical cloud submodel is included only for altitudes of Point V equal to or greater than the highest altitude (12 km) of a cloud top in that submodel. The general procedure is to first consider a given altitude (now denoted by index IKM), nadir-J, and azimuth-K, just as with no clouds. With the air emission, ARCVA(IKM,J,L), along the line-of-sight (LOS) above 12-km altitude serving as a base value, we obtain a distribution function for the additional radiance corresponding to cloud-free-LOS (CFLOS) and cloudy-LOS extending below 12-km altitude. Because there are 159 cloud configurations in the statistical cloud model, this distribution function has 160 members for nighttime and 161 members for daytime:

159 for cloud-top emission and (if daytime) cloud-reflected solar radiation

1 for Earth's surface emission and air emission below 12-km altitude (for a 1-leg CFLOS)

1 for Earth's surface emission, air emission below 12-km altitude, and (if daytime) ground-reflected solar radiation (for a 2-leg CFLOS, obtaining for daytime).

The last two members are the weighted contributions for CFLOS conditions. (Owing to certain simplifications made in the cloud modeling, there are actually only 9 and not 159 distinct values in the distribution for a cloudy-LOS.) Having determined the distribution function for a given look direction from Point V, we form the integral distribution and compute selected percentiles (XXX = 10, 25, 50, 90, 100) of the integral distribution, RXXX(K,L), at implicit altitude-IKM, implicit nadir-J, and explicit azimuth-K. Values of RXXX(K,L) are averaged over azimuth angles to give RXXXA(IKM,J,L). Values of ARCVA(IKM,J,L) and RXXXA(IKM,J,L) are averaged over nadir angles to give ARCVN(IKM,L) and RXXXN(IKM,L), respectively.

Since the inclusion of the broad-band index JBAND was a late change (March 1980), we elected not to modify the arrays ARCVN(IKM,L) and RXXXN(IKM,L) to provide for an explicit dependence on the index JBAND as we did for the array UPRADN(I,L,JBAND). This limitation must be remembered and removed if JBAND > 1 and if clouds are included, unless one adopts the GRC definition of UPRADN(I,L,JBAND) (which we give later).

It would probably be more conceptually satisfying if one could perform azimuth- and nadir-averages for each of the cloud configurations, so that one could end up with a distribution function at a given altitude instead of averaged percentile-values. Such a procedure was not followed.

The natural cloud model does not include air emission between cloud tops and 12-km altitude. Hence, such air emission is not included here, either.

6.1-3 Dependence on Other Models

It will be recognized, of course, that the Upwelling Radiation Model depends heavily on other models which we have integrated into it. Obviously

required are the models described in earlier sections of this report (Earth Surface Characterization in Sections 2 and 3, Solar Radiation in Section 4, Earth Surface Radiance in Section 5) as well as the SAI models described elsewhere for the Ambient Atmosphere (Volume 14a-1) and Natural Clouds (Volume 24). In addition, highly essential ingredients are provided by the G.E. Tempo models for Atmospheric Thermal Emission (Volumes 28 and 31) and Molecular Transmittance (Volumes 28 and 31) and the Visidyne, Inc./AFGL model for Atmospheric Aerosols (Volume 25). Explicit recognition of the pertinent routines is given later.

6-2 SUBROUTINE UPWELL

6-2.1 Formulas

6-2.1.1 Geometry

Here we derive the formulas associated with the characteristic Points P.

In Figure 6-1, consider the Point V at altitude h and the ray VT tangent to the Earth's surface. Then, for the right triangle OTV, we have

$$s_T^2 + R^2 = (R+h)^2$$

or

$$s_T = (2h\,R + h^2)^{1/2}.$$

The nadir angle β_T at Point V for the tangent ray is

$$\beta_T = \cos^{-1}\,[s_T/(R+h)].$$

The solid angle between nadir angles β_1 and β_2 is

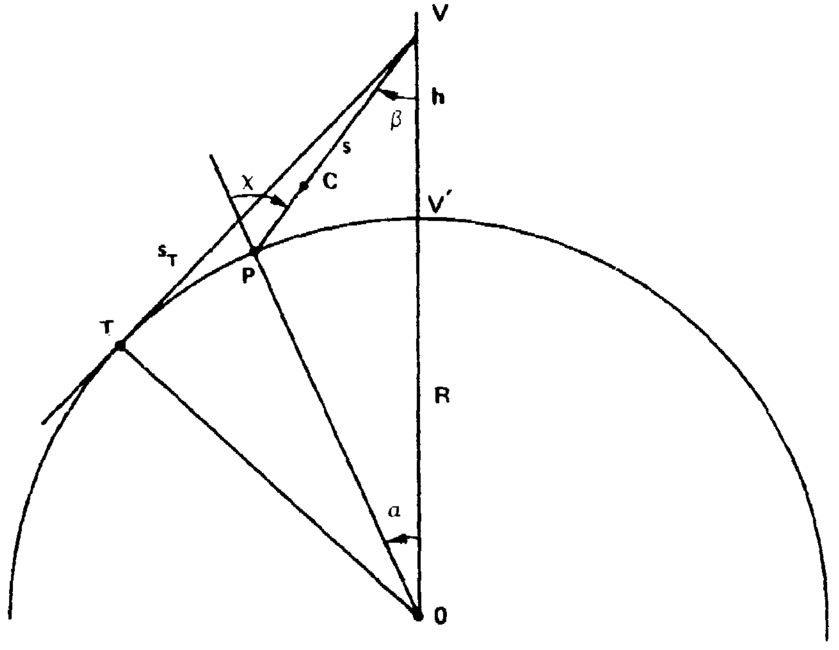


Figure 6–1. Geometry for characteristic points on Earth's surface.

$$\Omega(\beta_1,\beta_2) = 2\pi \int_{\beta_1}^{\beta_2} \sin\beta \, d\beta = 2\pi \, (\cos\beta_1 - \cos\beta_2).$$

For $\beta_1 = 0$, we have

$$\Omega(0,\beta_2) = 2\pi \, (1 - \cos\beta_2).$$

For $\beta_1 = 0$ and $\beta_2 = \beta_T$, we have

$$2\pi\Omega_T' \equiv \Omega(0,\beta_T) = 2\pi(1 - \cos\beta_T).$$

Consider now the oblique triangle OPV for which

$$\alpha + \beta = \chi$$

where, at Point P, χ is the zenith angle of Point V. From the law of sines, we have

$$\frac{\sin(\pi-\chi)}{R+h} = \frac{\sin\chi}{R+h} = \frac{\sin\alpha}{s} = \frac{\sin\beta}{R} .$$

Consider now the fractiles $(n-1/2)/n_\beta$ (with $n=1, 2, \ldots, n_\beta$) of the normalized solid angle Ω_T'. The corresponding angles and distances of interest are:

$$\cos\beta_n = 1 - \frac{n-\frac{1}{2}}{n_\beta}\,\Omega_T'$$

$$\beta_n = \cos^{-1}(\cos\beta_n)$$

$$\chi_n = \sin^{-1}\left[\left(1 + \frac{h}{R}\right)\sin\beta_n\right]$$

$$\alpha_n = \chi_n - \beta_n$$

$$s_n = R\sin\alpha_n/\sin\beta_n .$$

These quantities of interest are tabulated in Table 6-1 for altitudes of 1, 10, and 100 km. Ω_T' has the values of 0.982, 0.944, and 0.825 for h = 1, 10, and 100 km.

For a Point C at 12-km altitude on the ray $\overrightarrow{VP}$, we have

Table 6-1. Geometrical quantities of interest for Point-V at altitudes of 1, 10, and 100 km.

h = 1 km

n	β_n	χ_n	α_n	$R\alpha_n$	s_n
1	18.03	18.03	.00293	0.33	1.05
2	31.50	31.50	.00551	.61	1.17
3	41.02	41.03	.00782	.87	1.33
4	48.99	49.00	.01034	1.15	1.52
5	56.08	56.10	.01338	1.49	1.79
6	62.63	62.64	.01737	1.93	2.18
7	68.80	68.83	.02320	2.58	2.77
8	74.73	74.76	.03298	3.67	3.80
9	80.50	80.55	.05386	5.99	6.07
10	86.16	86.30	.1365	15.18	15.21

h = 10 km

n	β_n	χ_n	α_n	$R\alpha_n$	s_n
1	17.67	17.70	.0286	3.19	10.50
2	30.86	30.92	.0538	5.98	11.65
3	40.18	40.26	.0760	8.45	13.10
4	47.96	48.06	.0998	11.10	14.95
5	54.89	55.01	.1281	14.24	17.41
6	61.26	61.43	.1644	18.28	20.85
7	67.27	67.48	.2156	23.98	26.00
8	73.02	73.32	.2971	33.03	34.54
9	78.60	79.06	.4551	50.61	51.62
10	84.08	85.02	.9414	104.68	105.24

h = 100 km

n	β_n	χ_n	α_n	$R\alpha_n$	s_n
1	16.51	16.78	.2668	29.7	104.4
2	28.80	29.30	.4957	55.1	114.4
3	37.46	38.15	.6922	77.0	126.6
4	44.66	45.55	.8956	99.6	141.7
5	51.04	52.16	1.1257	125.2	161.0
6	56.88	58.29	1.4052	156.2	186.5
7	62.36	64.13	1.7700	196.8	222.1
8	67.58	69.87	2.2914	254.8	275.6
9	72.61	75.76	3.1488	350.1	366.7
10	77.50	82.58	5.0774	564.6	577.5

$$\frac{\sin(\pi - \chi_c)}{R+h} = \frac{\sin \beta}{R+C_{12}}$$

or

$$\sin \chi_c = \frac{R+h}{R+C_{12}} \sin \beta$$

where, at Point C, χ_c is the zenith angle of Point V.

The Earth-central angle α_c is

$$\alpha_c = \chi_c - \beta.$$

6-2.1.2 Radiance

Here we record the general formulas used to compute the radiance directed along the paths from Point P to Point V and from Point C to Point V, shown in Figures 6-2 and 6-3.

6-2.1.2.1 No Clouds

For no clouds (or for Point-V altitudes below 12-km when clouds are included), the radiance may be written as

$$[\text{Radiance}]_{pv} = [\text{Air radiance}]_{pv} + [\text{Ground emission radiance}]_p$$

$$\times \text{TTPV(L)} + [\text{Ground-reflected solar radiance}]_p \times \text{TTSPV}$$

or

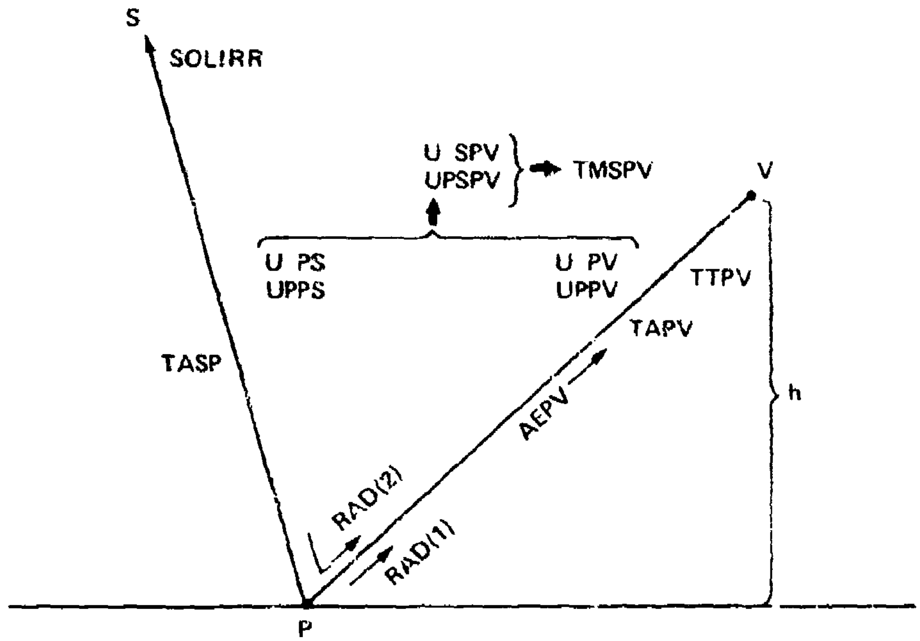


Figure 6-2. Geometry and ingredients for radiance calculation along path $\overrightarrow{PV}$ without clouds.

$$\mathrm{UPRAD(K,L)} = \underbrace{\mathrm{AEPV(L)} + \mathrm{RAD(1)} \times \mathrm{TTPV(L)}}_{\mathrm{UPRAD_0(K,L)}} + \mathrm{RAD(2)} \times \mathrm{TTSPV(L)}$$

where

TTPV(L) = Total transmittance along $\overrightarrow{PV}$

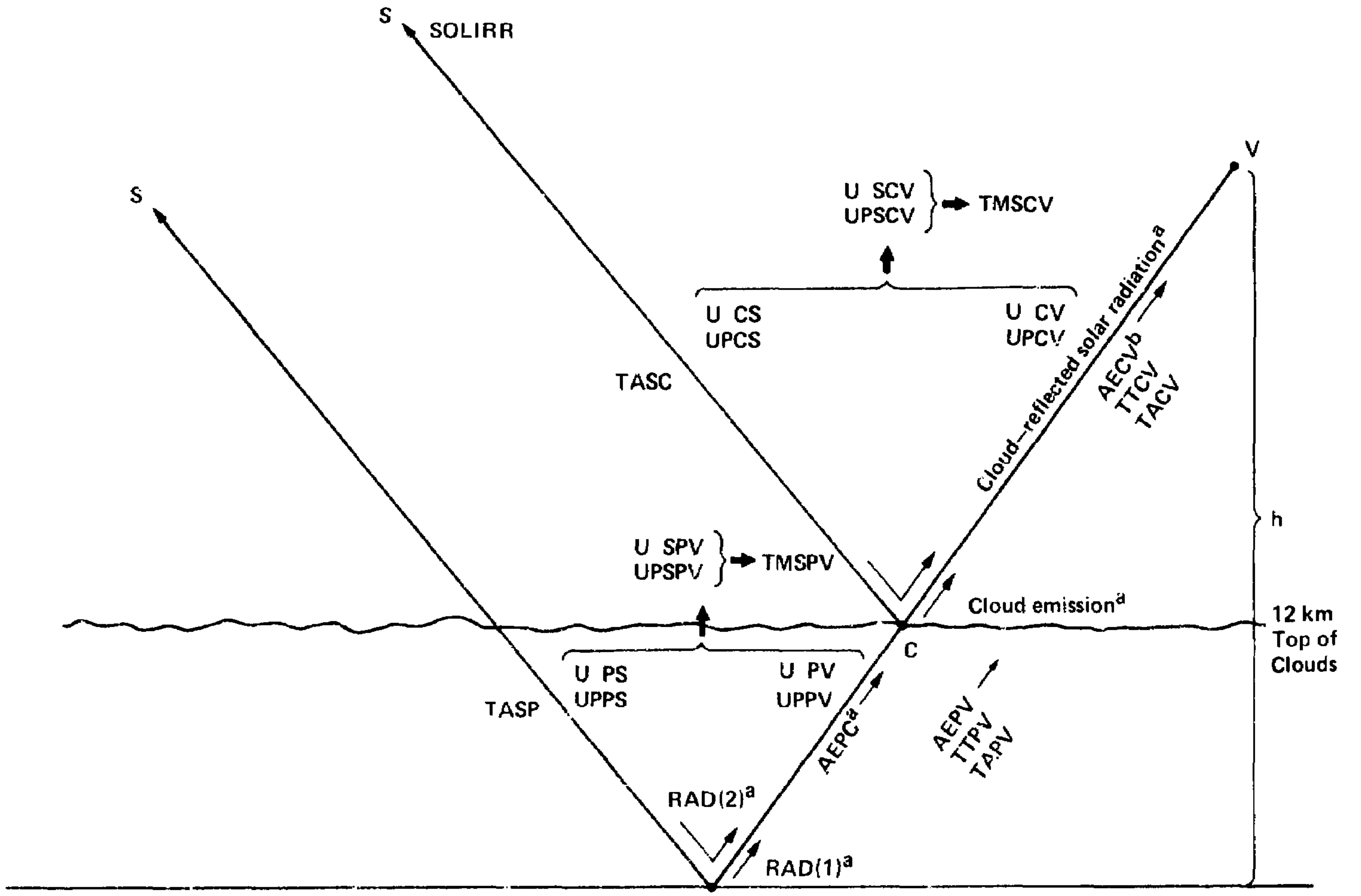
= Product of molecular transmittance and aerosol transmittance

TTSPV(L) = Total transmittance along $(\overrightarrow{SP} + \overrightarrow{PV})$

= (Molecular transmittance) x (Aerosol transmittance)

= TMSPV(L) x [TASP(L) x TAPV(L)].

The molecular transmittance TMSPV depends on the path parameters for the entire path $(\overrightarrow{SP} + \overrightarrow{PV})$:



[a]Sometimes. [b]Always.

Figure 6–3. Geometry and ingredients for radiance calculation along path ($\grave{PC}$ + $\grave{CV}$) with clouds below 12 km.

U (M,N,1) = U PS(M,N,1) + U (M,N,2)
UP(M,N,1) = UPPS(M,N,1) + UP(M,N,2).

6-2.1.2.2 With Clouds ($h \geq 12$ km)

When clouds are included in the calculation on a statistical basis, the problem becomes much more complicated, as inferred from Figure 6-3. The general procedure is to compute the radiance with and without the clouds and (essentially) to weight the two results by the probabilities that the line-of-sight (LOS) from Point V intersects the clouds or does not intersect the clouds (discussed in Section 6-2.3).

If the LOS intersects the clouds, the radiance may be written as

$$[\text{Radiance}]_{CV} = [\text{Air radiance}]_{CV} + [\text{Cloud emission radiance}]_C \times \text{TTCV(L)}$$

$$+ [\text{Cloud-reflected solar radiance}]_C \times \text{TTSCV(L)}$$

or

$$= \text{AECV(L)} + \text{EMISS(IDX)} \times \text{TTCV(L)} + \text{SOLIRR(L)} \times \text{TRANS(IDX)} \times \text{TTSCV(L)},$$

where

TTCV(L) = Total transmittance along $\overrightarrow{CV}$

= Product of molecular transmittance and aerosol transmittance

TTSCV(L) = Total transmittance along $(\overrightarrow{SC} + \overrightarrow{CV})$

= (Molecular transmittance) x (Aerosol transmittance)

= TMSCV(L) x [TASC(L) x TACV(L)].

The molecular transmittance TMSCV depends on the path parameters for the entire path $(\overrightarrow{SC} + \overrightarrow{CV})$:

$$U\ SCV(M,N,1) = U\ CS(M,N) + U\ CV(M,N)$$
$$UPSCV(M,N,1) = UPCS(M,N) + UPCV(M,N).$$

6-2.2 Input and Output Variables

The input and output variables for Subroutine UPWELL are described in Table 6-2.

6-2.3 Calculational Steps

A. Preliminaries

1. Set JBAND1 in /UPWELS2/.
2. Set Subpoint V' in /TECTOP/.
3. Determine solar conditions.
   - a. Solar zenith angle
   - b.1 If IDAYV = 0,
     REFAZI = 0.0, $\vec{RS}$ = 0.
   - b.2 If IDAYV = 1,
     - (1) Call GEOREA for REFAZI
     - (2) Call GEOXYZ for $\vec{RS}$ in /SORCE/
     - (3) Zero arrays USPV, UPSPV, USCV, UPSCV.
4. Set altitude of all Points P.
5. Initialize counter for cloud calculations, IKM = 0.

B. Altitude Loop (I=1,NALT(JBAND)≡NALTJ)

1. Advance altitude (of fictitious detector) at Point V.
2. Call GEOXYZ for $\vec{RV} \equiv \vec{RD}$ in /SANDD/.
3. Get nadir angle for tangent ray and corresponding solid angle.
4. If IKM=1 (implies ZKM(I,JBAND) = 12.0), compute CFPS, the CFLOS for Path $\vec{PS}$ by using calls to CFLOSF in the following formula:

$$CFPS = \sum_{IC=1}^{5} CCOVER(IC,KMODEL) \times CFLOSF[ICC(IC),\ SOLZ]$$

with ICC(IC) = 1,4,6,9,11 for IC = 1,2,3,4,5.

Table 6-2. Input and output variables for Subroutine UPWELL.

INPUT VARIABLES

Argument List

MSM - Index for category of surface material (see Table 2-12 for Subroutine ESURF).

DD - Additional descriptor for selected surface material (see Table 2-12 for Subroutine ESURF).

WW, DW - Arrays of central wavenumbers and wavenumber-interval widths corresponding to broad-band index JBAND. (cm^{-1})

SPCULR - Logical parameter, passed to Subroutine SURRAD.
= .TRUE., Compute coordinates of specular reflection point on an assumed smooth horizontal water surface, provided MSM=2.
= .FALSE., Do not compute such coordinates.

LBINT - Word-5 (LHV) in GRC Dataset-BN (No. 114), List of Band-Interval Datasets (BI). Strictly, LBINT is the pointer (i.e., contains the (Q-array) address) for the list header of the Band-Interval Datasets-BI corresponding to Dataset-BN.

JBAND - Index for list of (broad) wavelength bands. (1 to 5)

AIRSOL Common

For L=1,NWAVEJ

TASP(L), TASC(L) - Aerosol transmittance for incoming solar rays to Point P on ground and Point C at 12-km altitude.

CLDFREQ Common

KMODEL - Index (1 to 11) characterizing a set of statistical averages of cloud-coverage categories, cloud types, and number of cloud layers for a given geographic region. Characterizes a specification of CCOVER(5,11) and CFREQ(17, 4, 11) in Block Data CDATA for KMODEL = 1,10; user must supply his own data for KMODEL=11.

For ICC=1,5; KM=KMODEL=1,11

(continued)

Table 6-2. Input and output variables for Subroutine UPWELL (Cont'd).

CCOVER(ICC,KM) - Fractional occurrence frequency of cloud-coverage category ICC for given KMODEL.

CLDWT Common

IDX - Index for length of arrays returned from Subroutine CLDWT. IDX equals 160 for a full set of 159 cloud-layer and cloud-type configurations and is less for a restricted set.

WT(I) I=1,IDX - Probability of configuration-I. IDX equaling 160 corresponds to a cloud-free line-of-sight.

TRANS(I) I=1,IDX-1 - Transfer coefficient for configuration-I. In NBR Module, geometry for transmission through clouds is not included; only geometry for reflection of solar ray from the highest-layer cloud in configuration-I is included. Attenuation is included (within the Natural Cloud Model) to 12-km altitude. (1/sr)

EMISS(I) I=1,IDX-1 - Thermal emission spectral radiance from the highest-layer cloud in configuration-I with attenuation computed (within the Natural Cloud Model) to 12-km altitude. [W/(km^2 sr μm)]

OPTIN1 Common

RADSW - Logical variable serving as option switch for atmospheric volume emission calculation; passed to Subroutine TRNSCO.
=.TRUE., Include call (from Subroutine TRNSCO) to Subroutine ATMRAD.
=.FALSE., Bypass call to Subroutine ATMRAD and perform transmittance calculation in Subroutine TRNSCO without air emission.

OPTION Common

TRNSOPT - Logical variable affecting complexity of molecular transmittance calculation (see Tables 7-3 and 6-10 for Subroutines TRANSB and TRANS). In Subroutine UPWELL, TRNSOPT is used only in the argument list for calls to Subroutine TRANS.

QNCNC Common

NCNC - A variable, set to NC after the double call to Subroutine STEPS in Subroutine TRNSCO, employed to facilitate being

(continued)

Table 6-2. Input and output variables for Subroutine UPWELL (Cont'd).

able to use zero-kilometer altitude in the NBR Module. For more information, see comments preceding label number 22 in Subroutine UPWELL.

SOLARP Common

SOLLAT, SOLLON - North latitude and east longitude of subsolar point. (radians)

For L=1,NWAVEJ

SOLIRR(L) - Solar spectral irradiance at the top of the Earth's atmosphere at wavenumber-index L. [$W/(cm^2\ cm^{-1})$]

UPWELS Common

UPWALT, UPWLAT, UPWLON - Surface altitude, north latitude, and east longitude of the sub-V-point at which the upwelling radiance is computed. (km, radians, radians)

For I=1,NALTJ; M JBAND=1,NBANDS

NALT(M) - Number of altitudes ZKM(I,M) for (broad) wavelength-band index JBAND. Defines NALTJ.

ZKM(I,M) - Altitudes of Point V above UPWALT at which upwelling radiance is computed. (km)

NNADIR, NAZI - Number of nadir and azimuth angles at Point V at which upwelling radiance is computed.

NWAVE(M) - Number of wavenumbers at which the upwelling spectral radiance is to be computed for (broad) wavelength-band index JBAND. Defines NWAVEJ.

CLDFLG - Index for optional inclusion of natural clouds
=0., Clouds are not included.
=1., Clouds are included.

OUTPUT VARIABLES

FLAGS Common (differs from GRC's)

ITFLAG - Flag indicating the diurnal condition at Point V', for use by Subroutine CLDWT in the Natural Cloud Module.

(continued)

Table 6-2. Input and output variables for Subroutine UPWELL (Cont'd).

		=0, Sun is below the horizon. =1, Sun is above the horizon.
POSITN Common		
POSALT, POSLAT, POSLON	-	Altitude, north latitude, and east longitude of Point P at which line-of-sight (from fictitious detector at Point V) intersects Earth's surface. (km, radians, radians)
C12ALT, C12LAT, C12LON	-	Altitude, north latitude, and east longitude of Point C at which line-of-sight (directed toward Point P from fictitious detector at Point V) intersects the 12-km altitude surface. (km, radians, radians)
SANDD Common		
XS, YS, ZS	-	Earth-centered Cartesian coordinates of the sun. The orientation of the system is shown in Figure 5-5. (km)
XD, YD, ZD	-	Earth-centered Cartesian coordinates of the fictitious detector at Point V. (km)
UL, VL, WL	-	Direction cosines of Point P from Point V.
SORCE Common		
(Solar coordinates are needed in Subroutine TRANSF of the Natural Cloud Module.)		
NSORCE	-	Number of sources. Set to 1 in data statements.
HSORCE(1)	-	Altitude of sun (RSUN), set in data statement. (km)
RSORCE(1)	-	Radius of source. True value for sun is not relevant for this application in the NBR Module. Set to 0.0 in data statement.
THETAS, PHIS	-	Colatitude and east longitude of subsolar point. (degrees)

(continued)

Table 6-2. Input and output variables for Subroutine UPWELL (Cont'd).

TECTOR Common

DETALT, DETLAT, DETLON	-	Altitude, north latitude, and east longitude of fictitious detector at Point V. (km, radians, radians)

* *

o Note: UPRAD(K,L) (in /UPWELS3/), UPRADA(I,J,L) (in /UPWELS3/), and UPRADN(I,L,JBAND) (in /UPWELS/) are cloud-free results. For results which also include cloud effects for altitudes ≥12 km, use the corresponding arrays RXXX(K,L), RXXXA(I,J,L), and RXXXN(I,L), all in /UPWELS1/. To these arrays one must add, respectively, the base-value quantities ARCVA(I,J,L), ARCVA(I,J,L), and ARCVN(I,L) (in /UPWELS1/).

o In the GRC version, for altitudes ≥12 km and if clouds are included, the array UPRADN(I,L,JBAND) is reset as

UPRADN(I,L,JBAND) = RO50N(IKM,L) + ARCVN(IKM,L),

which is transferred through /UPWELS/ to (the GRC) Subroutine UPWELT. Thus, in the GRC version, for altitudes ZKM ≥12 km, UPRADN is not the cloud-free result but the 50-percentile of the radiance distribution function for statistical clouds (if included in the problem).

* *

UPWELS Common

IDAYV	-	Index for diurnal condition at sub-V-point. =0, Solar zenith angle > 90° =1, Solar zenith angle ≤ 90°.

For I=1,NALTJ; L=1,NWAVEJ; M≡JBAND=1,NBANDS

UPRADN(I,L,M)	-	Nadir-averaged value of UPRADA(I,J,L). [$W/(cm^2\ sr\ cm^{-1})$]
IKM	-	Index for number of altitudes at which calculations are made when clouds are included (used in Subroutine SURRAD).

UPWELS1 Common

For I=1,NALTJ; J=1,NNADIR; K=1,NAZI; L=1,NWAVEJ; M≡JBAND=1,NBANDS

(continued)

Table 6-2. Input and output variables for Subroutine UPWELL (Cont'd).

ARCVA(I,J,L)	-	When clouds are considered (ZKM(I,M) $\geq$ 12.0), a component of the upwelling spectral radiance received at Point V (at altitude-I), from air emission above 12-km altitude, along a ray directed to Point P on the Earth's surface (at nadir-J and independent of azimuth-K). [W/(cm^2 sr cm^{-1})]
ARCVN(I,L)	-	Nadir-averaged value of ARCVA(I,J,L) for ZKM(I,M) $\geq$ 12.0 km. [W/(cm^2 sr cm^{-1})]
For XXX = 10, 25, 50, 90, 100		
RXXX(K,L)	-	XXX-percentile of the integral distribution of the total (including that from statistical clouds) natural upwelling spectral radiance received at Point V for wavenumber-L (at implicit altitude-IKM above surface material-MSM) along a ray directed to Point P on Earth's surface (at implicit nadir-J and explicit azimuth-K). [W/(cm^2 sr cm^{-1})] **Note: RXXX(K,L) does not include ARCVA(I,J,L). Currently, UPRAD(K,L) and RXXX(K,L) are being written in binary form on logical unit No. 8, for all appropriate altitudes and nadirs.
RXXXA(I,J,L)	-	Azimuth-averaged value of RXXX(K,L). [W/(cm^2 sr cm^{-1})]
RXXXN(I,L)	-	Nadir-averaged value of RXXXA(I,J,L). [W/(cm^2 sr cm^{-1})]
UPWELS2 Common		
JBAND1	-	Same as JBAND, but made available to Subroutine SURRAD to facilitate print.
UPWELS3 Common		
For I=1,NALTJ; J=1,NNADIR; K=1,NAZI; L=1,NWAVEJ		
UPRAD(K,L)	-	Natural upwelling spectral radiance received at Point V (at altitude-I above surface material-MSM) along a ray directed to Point P on Earth's surface (at nadir-J and azimuth-K). (Implicitly, I=1,NALTJ; J=1,NADIR. I- and J-dependences are not stored so user must print UPRAD(K,L) immediately after computation if he wants to see them. Currently, UPRAD(K,L) and RXXX(K,L) are being written in binary form on logical unit No. 8, for all appropriate altitudes and nadirs.) [W/(cm^2 sr cm^{-1})]
UPRADA(I,J,L)	-	Azimuth-averaged value of UPRAD(K,L). [W/(cm^2 sr cm^{-1})]

C. Nadir Angle Loop (J=1,NNADIR)

1. Advance fractile (FRCTL) of tangent solid angle (OMEGAT(I)).
2. For fractile FRCTL, get
   a. Nadir angle (BETA).
   b. Zenith angle (CHI) of $\overrightarrow{PV}$.
   c. Earth-central angle (ALPHA).
   d. If clouds:
      (1) Zenith angle (CHIC) of $\overrightarrow{CV}$.
      (2) Earth-central angle (ALPHAC).
3. Initialize azimuth loop (number of azimuths and azimuth angle). If IDAYV = 0 or MSM = 1, set NAZI = 1.

D. Azimuth Angle Loop (K=1,NAZI)

1. Allow solar specular point to be computed (at most) once per altitude.
2. Advance azimuth angle.
3. Call AGAGEO to set latitude and longitude of Point P in /POSITN/.
4. Call GEOXYZ to get $\overrightarrow{RP}$ and thence direction cosines (UL,VL, WL) for /SANDD/.
5. If clouds:
   a. If IKM=1, Point C is at Point V and $\overrightarrow{RC} = \overrightarrow{RV}$.
   b. If IKM >1:
      (1) Call AGAGEO to set latitude and longitude of Point C in /POSITN/.
      (2) Call GEOXYZ to get $\overrightarrow{RC}$ for later use in call to TRNSCO.
6. Initialize position (FILPOS) of file LTMTE (necessary if TRNSOPT = .FALSE.).

E. Wavenumber Loop (L=1,NWAVE(JBAND)≡NWAVEJ)

1. Advance central wavelength (ZLAM)
2 Call SURRAD to get:
   a. At Point P:
      (1) Emitted radiance, RAD(1); for $L \geq 1$.

(2.1) Unattenuated reflected solar radiance, RAD(2); for $L \geq 1$.

(2.2) Path parameters [UPS(IT,N,1) and UPPS(IT,N,1)] for path $\overrightarrow{SP}$; for L=1.

(3) Aerosol transmittance, TASP(L) through /AIRSOL/, for path $\overrightarrow{SP}$; for $L \geq 1$.

b. At Point C (if IKM=1):

(1) Path parameters [UCS(IT,N) and UPCS(IT,N)] for path $\overrightarrow{SC}$; for L=1.

(2) Aerosol transmittance, TASC(L) through /AIRSOL/, for path $\overrightarrow{SC}$; for $L \geq 1$.

3. Call TRNSCO($\overrightarrow{PV}$) to get for path $\overrightarrow{PV}$:

a. (Derived from Word-8, -7, and -5 of Dataset-BI, obtained by calling PREV):
Aerosol transmittance, TAPV(L);
Total (molecular and aerosol) transmittance, TTPV(L);
Air emission, AEPV(L).

b. From XYZCOM Common:
Path parameters, U(IT,N,2) and UP(IT,N,2), preserved as UPV(IT,N) and UPPV(IT,N).

4. Compute sum (temporarily defined as UPRAD(K,L) and recognized as azimuthally independent) of (1) the Earth's surface radiance RAD(1), multiplied by the total transmittance TTPV(L) along $\overrightarrow{PV}$, and (2) the atmospheric emission AEPV(L) along $\overrightarrow{PV}$:

$$[\text{UPRAD}(K,L)]_{old} = \text{RAD}(1) \times \text{TTPV}(L) + \text{AEPV}(L) \quad (K=1,\text{NAZI}),$$

which is the upwelling spectral radiance, for implicit nadir index-J, at night (IDAYV=0) and for no clouds.

5. If clouds, call TRNSCO($\overrightarrow{CV}$) to get for path $\overrightarrow{CV}$:

a. (Derived from Word-8, -7, and -5 of Dataset-BI, obtained by calling PREV):
Aerosol transmittance, TACV(L);
Total (molecular and aerosol) transmittance, TTCV(L);
Air emission.

b. From XYZCOM Common:

Path parameters, U and UP, preserved as UCV and UPCV.

6. Preserve AECV(L), which is azimuthally independent, with a notation to indicate it is the azimuth average for the current values of IKM, J, and L:

ARCVA(IKM,J,L) = AECV(L).

7. Set ITFLAG in /FLAGS/ equal to IDAYV, for use in Subroutine TRANSF when called by Subroutine CLDWT.

8. Call CLDWT to obtain through /CLDWT/ the arrays WT, EMISS, and TRANS of lengths IDX=160, IDX-1=159, and IDX-1=159, respectively. IDX equals 160 for a full set of 159 cloud configurations. WT is the array for weights corresponding to the various cloud configurations or sets; at 12-km altitude (Point C) along $\overrightarrow{PV}$, EMISS is the array for cloud-top emission radiances and (if IDAYV=1) TRANS is the array for the (irradiance-to-radiance) transfer coefficients for cloud-top reflection of solar radiation. WT(M), for any of the 10 location-season averaged statistical cloud models (KMODEL=1,10), is the probability that (a) the cloud-configuration set indicated by the index M occurs and (b) the detector's LOS at zenith angle CHI intersects the cloud-configuration set. The probability of the detector's LOS intersecting clouds is Σ WT(M), (M=1,159).

9. Continue with following steps:

   a. To facilitate computing the radiance distribution function resulting from the statistical treatment of natural clouds, start forming a new radiance distribution function (UPRADC) and corresponding weights (WTC).

   b. To facilitate assessing the relative importance of emission and reflection contributions, preserve the emission component of UPRADC in another array (UPRDC1).

   c. Multiply the spectral radiance from the Natural Cloud Module, expressed in $W/(km^2\ sr\ \mu m)$, by 1.0E-14 $\times$ $(ZLAM)^2$ to obtain $W/(cm^2\ sr\ cm^{-1})$.

d. Include transmittance between Points C and V. For M=1,159:

$[UPRADC(M)]_{old}$ = 1.0E-14 x $(ZLAM)^2$ x EMISS(M) x TTCV(L)

UPRDC1(M) = $[UPRADC(M)]_{old}$

WTC(M) = WT(M)

$$SUMWTC = \sum_{M=1}^{159} WTC(M).$$

e. Now use fact that the radiance at Point V due to air emission along $\overrightarrow{PV}$ can be separated into two portions:

AEPV(L) = AEPC(L) x TTCV(L) + AECV(L)

or

AEPC(L) x TTCV(L) = AEPV(L) - AECV(L).

Hence we need to subtract AECV(L) from UPRAD(K,L) in order that UPRADC(160) will be the air emission along $\overrightarrow{PC}$ but attenuated along $\overrightarrow{CV}$.

UPRADC(160) = UPRAD(K,L) - AECV(L)

UPRDC1(160) = UPRADC(160).

f. We need the mean probability of a cloud-free line-of-sight (CFLOS) along $\overrightarrow{PC}$ (at zenith angle CHI at Point P corresponding to nadir angle BETA at Point V). As noted in Step 8, the probability of the detector's LOS intersecting clouds is SUMWT = Σ WT(M), (M=1,159). Hence we take (1-SUMWT) as the desired probability of a CFLOS, CFPV:

CFPV = 1-SUMWTC

WTC(160) = CFPV.

This WTC(160) obtains for night. The daytime value is set later.

10. If IDAYV=1, we must include the surface-reflected solar radiation:

a. In Step 3b, we preserved the path parameters along $\overrightarrow{PV}$ as UPV(IT,N) and UPPV(IT,N). We now add the parameters for path segments $\overrightarrow{SP}$ and $\overrightarrow{PV}$ and preserve as USPV and UPSPV arrays.

U SPV(IT,N) = U PS(IT,N) + U PV(IT,N).

UPSPV(IT,N) = UPPS(IT,N) + UPPV(IT,N).

b. Call TRANS(...,USPV,UPSPV,...) to get the total molecular transmittance (TMSPV(L)) for the total path ($\overrightarrow{SP}+\overrightarrow{PV}$).

c. To get the aerosol transmittance for the total path ($\overrightarrow{SP}+\overrightarrow{PV}$), use TASP(L) returned through /AIRSOL/ from call to Subroutine SURRAD and TAPV(L) from Subroutine TRNSCO's call to Subroutine ATMRAD for path $\overrightarrow{PV}$.

d. Thus the total transmittance for the surface-reflected solar ray along the total path ($\overrightarrow{SP}+\overrightarrow{PV}$) is

TTSPV(L) = TMSPV(L) x [TASP(L) x TAPV(L)].

e. The total upwelling radiance along the path $\overrightarrow{PV}$ (without clouds) is

$[\mathrm{UPRAD(K,L)}]_{new} = [\mathrm{UPRAD(K,L)}]_{old} + \mathrm{TTSPV(L)} \times \mathrm{RAD(2)}$

where only RAD(2) may depend on azimutn, which it will for non-Lambertian surface materials (MSM>1). The first term is the sum of the attenuated ground-surface emission and air emission along path $\overrightarrow{PV}$ (obtained in Step E.4) and the second term is the product of the unattenuated surface-reflected solar radiance (obtained from Step E.2.a.(2.1)) and the total transmittance (obtained from Step E.10.d).

11. If IDAYV=1 and clouds are present, one must include the cloud-reflected solar radiation.

a. We must convert the transfer coefficients (TRANS, from Step E.8) into radiances for the cloud-reflected solar radiation. To do so, we need the solar spectral irradiance E[W/(cm^2 cm^{-1})] (normal to the path to the sun) at the 12-km altitude point along the path $\overrightarrow{VP}$. We use the quantity SOLIRR(L) = E, previously obtained

from Subroutine SURRAD's call to SOLRAD and available through /SOLARP/.

b. We include air transmittance [TTSCV(L)] above 12-km altitude along the total path $(\vec{SC}+\vec{CV})$. TTSCV(L) is given by the product of the molecular transmittance [TMSCV(L)] and the aerosol transmittance [TASC(L) x TACV(L)]. TMSCV(L) will be computed by Subroutine TRANS, given the path parameters USCV and UPSCV. From Subroutine TRNSCO's call to PATH (Step E.5.b), we have the path parameters U(IT,N,2) and UP(IT,N,2) (which we saved as UCV(IT,N) and UPCV(IT,N) for the path $\vec{CV}$. The path parameters UCS(IT,N) and UPCS(IT,N) were obtained from the call to Subroutine SURRAD [Step E.2.b.(1)]. Add to the path parameters and preserve as USCV and UPSCV arrays.

U SCV(IT,N) = U CS(IT,N) + U CV(IT,N)

UPSCV(IT,N) = UPCS(IT,N) + UPCV(IT,N).

c. Call TRANS(...,USCV,UPSCV,...) to obtain the total molecular transmittance TMSCV(L) for the total path $(\vec{SC}+\vec{CV})$.

d. To get the aerosol transmittance for the total path $(\vec{SC}+\vec{CV})$, use TASC(L) returned through /AIRSOL/ from call to Subroutine SURRAD and TACV(L) from Subroutine TRNSCO's call to Subroutine ATMRAD for path $\vec{CV}$.

e. Thus the total transmittance for the cloud-reflected solar ray along the total path $(\vec{SC}+\vec{CV})$ is

TTSCV(L) = TMSCV(L) x [TASC(L) x TACV(L)].

f. A contribution to the total upwelling radiance along the path $\vec{CV}$ (with clouds at or below Point C) is

$$[\mathrm{UPRADC(M)}]_{new} = [\mathrm{UPRADC(M)}]_{old} + \mathrm{SOLIRR(L)} \times \mathrm{TRANS(M)} \times \mathrm{TTSCV(L)} \quad (\mathrm{M}=1,159)$$

where only the transfer coefficient TRANS(M) depends on azimuth. The first term is the cloud-surface emission attenuated along path $\vec{CV}$ (obtained in Step

E.9.d) and the second term is the product of the unattenuated cloud-surface-reflected solar radiance [SOLIRR(L) x TRANS(M)] and the total transmittance (obtained from Step E.11.e).

g. WTC(160) needs to be reset for daytime conditions. We multiply the probability of the (nighttime) one-leg CFLOS by the probability of not having the second (daytime) leg:

   WTC(160) = CFPV x (1.0 - CFPS),

   where CFPV was set in Step E.9.f and CFPS was set in Step B.4.

h. For daytime, the arrays UPRADC, UPRDC1, and WTC must be augmented by inclusion of members for a two-leg CFLOS:

   UPRDC1(161) = UPRADC(160)

   UPRADC(161) = UPRADC(160) + RAD(2) x TTSPV(2)

   WTC(161) = CFPS x CFPV

   where UPRADC(160) was set in Step E.9.e, RAD(2) in Step E.2.a.(2.1), and TTSPV(L) in Step E.10.d.

12. For clouds, day or night, the distribution-function arrays must be processed.

   a. Augment each of the three arrays (UPRADC, UPRDC1, and WTC) with a zero-value member, which allows Subroutine LINEAR to interpolate within its given array if the weight of the normally smallest member exceeds the smallest fractile (now 0.10) for which an integral-distribution value is requested.

   UPRADC(II) = UPRDC1(II) = WTC = 0.0

   $$II = \begin{cases} 161 \text{ for night} \\ 162 \text{ for day.} \end{cases}$$

   b. Call SORTLJ to sort the radiance array UPRADC in increasing order and carry along the arrays UPRDC1 and WTC.

c. Sum the weights and normalize to unity (although, in principle, the weights are already so normalized).

d. Interpolate the array UPRADC (by calling LINEAR) to obtain the percentile values (called RXXX(K,L)) corresponding to XXX = 10, 25, 50, and 90 (i.e., WTC = 0.10, 0.25, 0.50, and 0.90). For XXX = 100, set RXXX(K,L) = UPRADC(II).

C'. Nadir Angle Loop (J=1,NNADIR) Completion

After completing the wavenumber and azimuth loops, compute averages over azimuth angles K at wavenumbers L=1,NWAVEJ; nadir angle J; and altitude I (or IKM for clouds).

$$\mathrm{UPRADA(I,J,L)} = \mathrm{(1/NAZI)} \sum_{K=1}^{NAZI} \mathrm{UPRAD(K,L)}$$

$$\mathrm{RXXXA(IKM,J,L)} = \mathrm{(1/NAZI)} \sum_{K=1}^{NAZI} \mathrm{RXXX(K,L)}$$

XXX = 10, 25, 50, 90, 100

D'. Altitude Loop (I=1,NALTJ) Completion

After completing the nadir loop, compute averages over nadir angles J at wavenumbers L=1,NWAVEJ and altitude I (or IKM for clouds):

$$\mathrm{UPRADN(I,L,JBAND)} = \mathrm{(1/NNADIR)} \sum_{J=1}^{NNADIR} \mathrm{UPRADA(I,J,L)}$$

$$\mathrm{ARCVN(IKM,L)} = \mathrm{(1/NNADIR)} \sum_{J=1}^{NNADIR} \mathrm{ARCVA(IKM,J,L)}$$

$$RXXXN(IKM,L) = (1/NNADIR) \sum_{J=1}^{NNADIR} RXXXA(IKM,J,L).$$

Since the inclusion of the index JBAND was a late change, we elected not to modify the arrays ARCVN(IKM,L) and RXXXN(IKM,L) to provide for an explicit dependence on the index JBAND as we did for the array UPRADN(I,L,JBAND). This limitation must be remembered and removed if JBAND >1 and if clouds are included, unless one adopts the GRC definition of UPRADN(I,L,JBAND), i.e., UPRADN(I,L,JBAND) = RO5ON(IKM,L) + ARCVN(IKM,L).

6-3 OTHER ROUTINES IN UPWELLING NATURAL RADIATION MODEL

Subroutine UPWELL, the principal routine in the Upwelling Natural Radiation Model, makes a number of calls as shown in Figure 6-4.

6-3.1 SAI Routines

The calls to the left of the vertical line in Figure 6-4 are related to the Natural Cloud Model. Subroutine GEOXYZ has been discussed in Section 5-4.1. Subroutine XMIT is described in Table 7-3a. The routines CFLOSF, CLDWT, SORTLJ, and LINEAR are part of the Natural Cloud Model; listings of them are in Volume 24 and brief descriptions of them are given here in Table 7-3a. Note that the listing of SORTLJ given here in Section 8 differs in an essential aspect from that in Volume 24 and must be used with the NBR Module (the listing in Volume 24 is satisfactory for its use there).

The routines AGAGEO, GEOREA, GEOTAN (called by GEOREA), REATAN (called by AGAGEO), and TANGEO (called by AGAGEO) provide coordinate transformations. They are described in Table 7-3a. Their input and output variables are given in Tables 6-3 through 6-7, respectively.

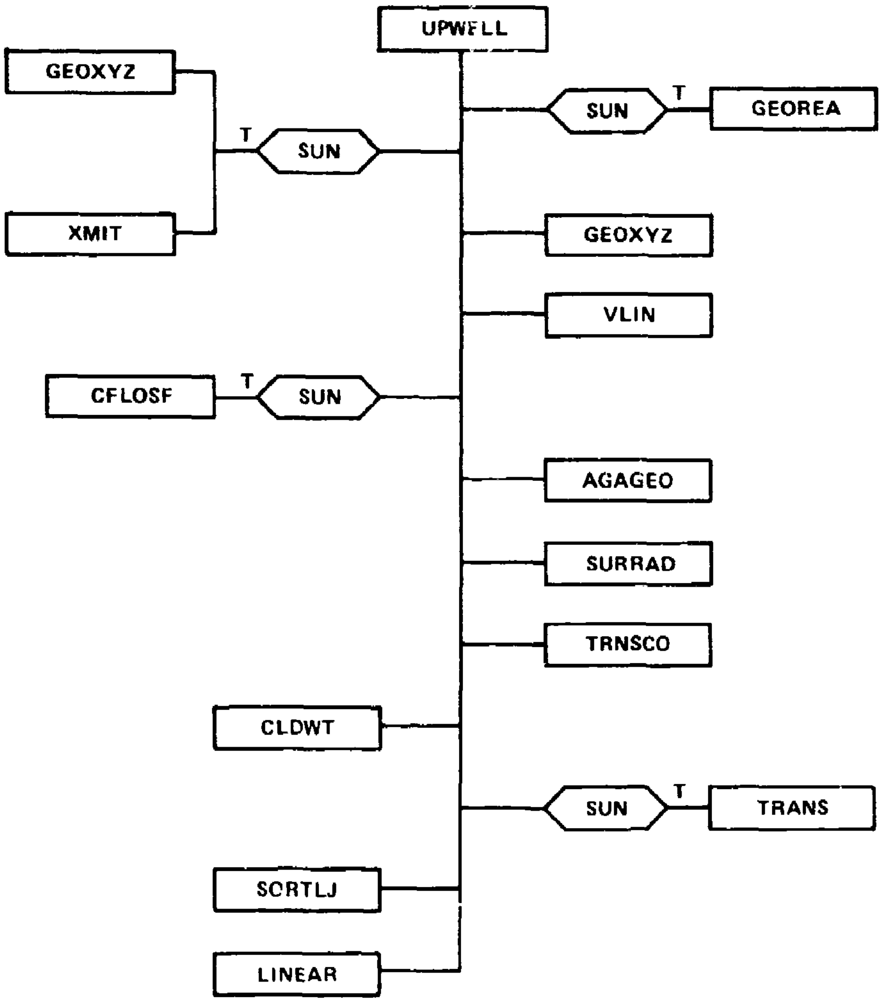


Figure 6–4. Routines called directly from the principal routine (UPWELL) in the Upwelling Natural Radiation Model. For subsequent calls, see Figure 7–1.

Table 6-3. Input and output variables for Subroutine AGAGEO.

INPUT VARIABLES		
Argument List		
HA1, GC1, GL1	-	Altitude, colatitude, and east longitude of Point 1. (cm, radians, radians)
AZ21, GA21	-	Azimuth angle and geocentric angle of Point 2 relative to Point 1. (radians)
HA2	-	Altitude of Point 2. (cm)
OUTPUT VARIABLES		
Argument List		
GC2, GL2	-	Colatitude and east longitude of Point 2. (radians)

Table 6-4. Input and output variables for Subroutine GEOREA.

INPUT VARIABLES		
Argument List		
HA1, GC1, GL1	-	Altitude, colatitude, and east longitude of Point 1. (cm, radians, radians)
HA2, GC2, GL2	-	Altitude, colatitude, and east longitude of Point 2. (cm, radians, radians)
OUTPUT VARIABLES		
Argument List		
SR21, EL21, AZ21	-	Slant range, elevation, and azimuth of Point 2 relative to Point 1. (cm, radians, radians)

Table 6-5. Input and output variables for Subroutine GEOTAN.

INPUT VARIABLES

Argument List

HA1, GC1, GL1	-	Altitude, colatitude, and east longitude of Point 1. (cm, radians, radians)
HA2, GC2, GL2	-	Altitude, colatitude, and east longitude of Point 2. (cm, radians, radians)

OUTPUT VARIABLES

Argument List

XE21, YN21, ZV21	-	X, Y, and Z coordinates of Point 2 relative to Point 1. (cm)

Table 6-6. Input and output variables for Subroutine REATAN.

INPUT VARIABLES

Argument List

SR, EL, AZ	-	Slant range, elevation angle, and azimuth angle of Point P. (cm, radians, radians)

OUTPUT VARIABLES

Argument List

XE, YN, ZV	-	X, Y, and Z coordinates of Point P. (cm)

Table 6-7. Input and output variables for Subroutine TANGEO.

INPUT VARIABLES

Argument List

HA1, GC1, GL1	-	Altitude, colatitude, and east longitude of Point 1. (cm, radians, radians)
ZE21, YN21, ZV21	-	X, Y, and Z coordinates of Point 2 relative to Point 1. (cm)

OUTPUT VARIABLES

Argument List

HA2, GC2, GL2	-	Altitude, colatitude, and east longitude of Point 2. (cm, radians, radians)

6-3.2 G.E. Tempo Routines (TRNSCO, ATMRAD, TRANS)

Three very important routines called either directly or indirectly by Subroutine UPWELL are Subroutines TRNSCO, ATMRAD, and TRANS. A brief description of the purpose of each of these routines is included in Table 7-3a. We have summarized their input and output variables here: Subroutine TRNSCO (Table 6-8), Subroutine ATMRAD (Table 6-9), and Subroutine TRANS (Table 6-10). Ewing et al. have given briefer statements about two of the routines in Volume 31: TRNSCO (p. 75) and TRANS (p.72, with flow chart on p. 73).

Table 6-8. Input and output variables for Subroutine TRNSCO.

INPUT VARIABLES

Argument List

For I=1,3

RX(I), RY(I), RZ(I)	-	Location vectors of Points X, Y, and Z which, respectively, are typically but not necessarily the locations of the detector, scattering site, and source. (cm)
LBINT	-	Word-5 (LHV) in GRC Dataset-BN (No. 114), List of Band-Interval Datasets (BI). Strictly, LBINT is the pointer (i.e., contains the (Q-array) address) for the List Header of the Band-Interval Datasets-BI corresponding to Dataset-BN.
RADSW	-	Logical variable serving as option switch for atmospheric volume emission calculation. =.TRUE., Include call (from Subroutine TRNSCO) to Subroutine ATMRAD. =.FALSE., Bypass call to Subroutine ATMRAD and perform transmittance calculation in Subroutine TRNSCO without air emission.

Dataset-BI (Band-Interval Dataset No. 115)

Q(1) = BNLO BI, Q(2) = BNHI BI	-	Low and high wavelengths for wavelength-band-index J. (μm)
Q(3) = WLO BI, Q(4) = WHI BI	-	Low and high wavenumbers for wavelength-band-index J. (cm^{-1})

XYZCOM Common

LTMTE	-	Binary file containing the band-model parameters which were derived in Subroutine TRANSB from the basic 5-cm^{-1} resolution data. Here in Subroutine TRNSCO, File LTMTE is rewound for use in Subroutine TRANS.

OPTION Common

TRNSOPT	-	Logical variable affecting complexity of molecular transmittance calculation (see Tables 7-8 and 6-10 for Subroutines TRANSB and TRANS). In Subroutine TRNSCO, TRNSOPT is used only in the argument list for the call to Subroutine TRANS, a call that occurs only if RADSW = .FALSE., which is not the case in the NBR Module.

(continued)

Table 6-8. Input and output variables for Subroutine TRNSCO (Cont'd).

OUTPUT VARIABLES

Description of the output requires caveats.

1. In the (rare) event the path should not intersect the shelled-atmosphere, then initialized values of Word-5 (if RADSW =.TRUE.), Word-7, and Word-8 of Dataset-BI are explicitly set here in Subroutine TRNSCO.

2. In the usual event that the path does intersect the atmosphere, there are two cases to consider:

2.1 RADSW = .TRUE. (Applies to NBR Module)

Subroutine ATMRAD is called to evaluate Words-5, -7, and -8 of Dataset-BI, but this dataset is not called here in TRNSCO and thus is not explicitly available in TRNSCO.

2.2 RADSW = .FALSE. (Does not apply to NBR Module)

Subroutine ATMRAD is not called. Hence, the calls that ATMRAD makes to get the transmittance calculations done must be made here in TRNSCO. In this case, Word-7 and -8 of Dataset-BI are explicitly available.

Definitions of Word-5, -7, and -8 of Dataset-BI follow.

Q(5)=BKGND BI - In-band-interval radiance (due to atmospheric emission) over the entire path length (which should have 1-leg and not 2-legs). [W/(cm^2 sr band-interval)]

Q(7)=TRANS BI - Product of molecular and aerosol transmittances over the entire path length.

Q(8)=IDSBX BI - Aerosol transmittance over the entire path length.

Note: This is a temporary use of Word-8 (and not the GRC dictionary use of Word-8). Here it is used to carry information to Subroutine UPWELL.

QNCNC Common

NCNC - A variable set to NC and made available to Subroutine UPWELL to facilitate being able to use zero-kilometer altitude in the NBR Module. For more information, see comments preceding label number 22 in Subroutine UPWELL.

Table 6-9. Input and output variables for Subroutine ATMRAD.

INPUT VARIABLES

Argument List

LOGIC - Logical variable.
=.TRUE., On first entry (for first path segment) from Subroutine TRNSCO (and is reset to .FALSE. in ATMRAD).
=.FALSE., On subsequent entries along the same path.

ISHELL(1), ISHELL(2) - INDX(I) and INDX(I+1) in call from Subroutine TRNSCO.

ISHELL(3) - Used in evaluating the logical variable TEST. ISHELL(3) will typically be equal to INDX(I+2), a positive quantity except on the last call to ATMRAD when the last path-segment is being treated, at which time ISHELL(3) will become equal to INDX(NC+1) which had been set to 0 in Subroutine STEP.

XFRAC(1), XFRAC(2) - XFRACS(I) and XFRACS(I+1) in call from Subroutine TRNSCO. To help understand the values and uses of XFRACS(I), (1) recall that the total path has NC-1 segments and NC end points of these segments and (2) see Table 5-8 for Subroutine STEP.

DS - DS(I+1) in call from Subroutine TRNSCO.
Note: It is always true that DS(1)=0 and DS(NC+1) = -1.0, where NC is the number of path segments plus one. ATMRAD will not be called with I=NC. (cm)

LBINT - Word-5 in GRC's Dataset-BN (No. 114). Strictly, LBINT is the pointer (i.e., contains the (Q-array) address) for the List Header of the Band-Interval Datasets-BI corresponding to Dataset-BN.

XYZCOM Common

FACT - Path resolution factor controlling the number of altitudes and spacing used in Subroutine SHELLS. See Table 7-9 for Subroutine SHELLS. Here in Subroutine ATMRAD, FACT is used to set TOL, which is used to test temperature differences across cells.

(continued)

Table 6-9. Input and output variables for Subroutine ATMRAD (Cont'd).

For J=1,NS

HSHELL(J), TS(J)	-	Altitude and temperature at boundary-J. (HSHELL(1)=0.0) (cm, deg K)

For I=1,2; N=1,10

U(I,N,2), UP(I,N,2)	-	Cumulative values of path parameters U (areal density) and UP (product of U and pressure P) for temperature-index-I and species-N at end of line segment DS. (cm at STP, atm-cm at STP)
NMOLS	-	Number (10) of molecular species in molecular transmittance model.
LTMTE	-	Binary file containing the band-model parameters which were derived in Subroutine TRANSB from the basic 5-cm^{-1} resolution data. Here in Subroutine ATMRAD, File LTMTE is rewound for use in Subroutine TRANS.

OPTION Common

TRNSOPT	-	Logical variable affecting complexity of molecular transmittance calculation (see Tables 7-8 and 6-10 for Subroutines TRANSB and TRANS). In Subroutine ATMRAD, TRANSOPT is used only in the argument list for the call to Subroutine TRANS.

Dataset-BI (Band-Interval Dataset No. 115)

Q(1)=BNLO BI, Q(2)=BNHI BI	-	Low and high wavelengths for wavelength-band-index J. (μm)
Q(3)=WLO BI, Q(4)=WHI BI	-	Low and high wavenumbers for wavelength-band-index J. (cm^{-1})

OUTPUT VARIABLES

Dataset-BI (Band-Interval Dataset No. 115)

Q(5)=BKGND BI	-	In-band-interval radiance to back of cell-DS. [W/(cm^2 sr band-interval)]
Q(7)=TRANS BI	-	Product of cumulative molecular and aerosol transmittance to back of cell-DS. (dimensionless)

(continued)

Table 6-9. Input and output variables for Subroutine ATMRAD (Cont'd).

Q(8)=IDSBX BI - Cumulative aerosol transmittance to back of cell-DS.

Note: This is the second of two temporary uses of Word-8 (and not the GRC dictionary use of Word-8). Here, it is used to carry information to Subroutine UPWELL.

Table 6-10. Input and output variables for Subroutine TRANS.

INPUT VARIABLES

Argument List

NTEMP - Number of temperatures in the atmospheric transmittance model (set to 10 in call from either Subroutine ATMRAD or TRNSCO).

M - Index for mode of transmittance calculation. Could be 1, 2,...,15. Within the NBR Module (where TRANS is called from ATMRAD, TRNSCO, and UPWELL), M is always 1. (In calls from Program EMISCAT, M is 1, 2 and is allowed values up to 15.) In Subroutine TRANS, M being 1 limits use of the U and UP arrays to their first-half values. This is consistent with the fact that within the NBR Module, Subroutine TRANS is always called with M set to 1, U set to U(1,1,2), and UP set to UP(1,1,2). This is also true for calls with M=1 from Program EMISCAT. But there, when $M \geq 2$, the calls are with U and UP, i.e., the entire arrays.

For I=1,NTEMP; N=1,NSPEC

U(I,N,1), UP(I,N,1) - Path parameters U (species-N areal density) and UP (product of U and pressure P) for temperature-index I and species-N. (cm at STP, atm-cm at STP)

FK(M) - FK(M) is used only if $M \geq 3$. In the NBR Module, M is always 1. (But for those calls with $M \geq 3$ from Program EMISCAT, FK(M) is a set of weights used to partition the path element.)

(continued)

Table 6-10. Input and output variables for Subroutine TRANS (Cont'd).

WDL, WDH - Lowest and highest wavenumber in the detector interval being used for which the transmittance is to be computed. (cm^{-1})

FAST - Logical variable determining complexity of transmittance calculation. In calls to Subroutine TRANS (from Subroutines ATMRAD, TRNSCO, and UPWELL within the NBR Module and from Program EMISCAT outside the NBR Module), FAST is set to TRNSOPT.

=.TRUE., Transmittance is based on single-level groups and statistical bands.

=.FALSE., Transmittance is based on multiple-level groups and random Elsasser bands.

In addition, note that for TRNSOPT=.TRUE., Subroutine TRANSB develops the band-model parameters for the user interval of interest and Subroutine TRANS uses these band-model parameters to compute the transmittance and optical depth for the same interval. But for TRNSOPT=.FALSE., Subroutine TRANSB develops band-model parameters for an interval with (probably but not necessarily) higher resolution than the user interval. Thus, to obtain the transmittance and optical depth for the user interval, Subroutine TRANS first computes the optical depth (XS_j) and transmittance [$\exp(-XS_j)$] for the higher-resolution interval j and then obtains the transmittance [TAU(IS)] and optical depth [ABC(IS)] for species-IS in the user interval by using the following expressions to perform the weighted sum over those higher-resolution intervals overlapping the user interval.

$$TAU(IS) = \sum_j F_j \exp(-XS_j)$$

$$ABC(IS) = \begin{cases} -\ln\,[TAU(IS)] & \text{for } 10^{-4} < TAU(IS) < 0.9999 \\ \sum F_j XS_j & \text{otherwise.} \end{cases}$$

These formulas are not given in Volume 2B.

For additional information regarding the consequences for Subroutine TRANS due to the two possibilities for TRANSOPT in Subroutine TRANSB, see Table 7-3 for Subroutine TRANSB.

(continued)

Table 6-10. Input and output variables for Subroutine TRANS (Cont'd).

FILPOS - Position of file LTMTE. Set to 1.E+04 in calls from Subroutine TRNSCO and ATMRAD.

XY Common

For I=1,10

TT(I) - Temperature array in atmospheric transmission model.

XYZCOM Common

LTMTE - Binary file containing the band-model parameters which were derived in Subroutine TRANSB from the basic 5-cm^{-1} resolution data. Equivalenced (in Subroutine TRANSB) to TAPOT, for which definition see Table 7-8 for Subroutine TRANSB.

* * * * *

For each read of File LTMTE, the 202 words are stored as:

WTL, WTH - Lower and higher wavenumbers of interval. (cm^{-1})

For I=1,10; N=1,10

SOD(I,N), DEI(I,N) - Mean absorption coefficient and inverse of mean line-spacing parameter (or the effective line density) for species-N at temperature-index-I for the wavenumber interval (WTL,WTH). [1/cm at STP, lines/(cm^{-1})]

* * * * *

NSPEC - NMOLS, the number (10) of species in the molecular transmittance model.

OUTPUT VARIABLES

Argument List

For N=1,NSPEC; M=1,15 but M=1 for NBR Module

TAU(N,M) - Transmittance for species-N. (dimensionless)
ABC(N,M) - Optical depth for species-N. (dimensionless)
TTBL(M) - Molecular transmittance of all the species for mode-M.

SECTION 7

NATURAL BACKGROUND RADIATION (NBR) MODULE

7-1 INTRODUCTION

The NBR Module is defined to be a complete computer program which integrates nine ROSCOE-IR models into a consistent, stand-alone module - similar to the way it exists in the ROSCOE-IR Program - for the purpose of developing and testing the capability to compute the natural upwelling spectral radiance as a function of altitude. Table 7-1 provides a guide to the nine modules so integrated; we also include the Dynamic Storage Allocation (DSA) System [SP-78] because it plays such an important role and it is an entity integrated into the NBR Module.

Table 7-1. Guide to modules integrated into the NBR Module.

Title	Model Number	Developer	ROSCOE Manual Volume Number
Ambient Atmosphere	1a	SAI/LJ	14a-1,14c
Atmospheric Aerosols	1c, 19:1c	VI	25
Natural Clouds	1d, 19:1d	SAI/PA	24
Atmospheric Thermal Emission	20b	GET	28,31
Molecular Transmittance	24d	GET	28,31
Earth Surface Characterization	23a	SAI/LJ	27, Sect. 2,3
Earth Surface Radiance	23b	SAI/LJ	27, Sect. 5
Upwelling Natural Radiation	23c	SAI/LJ	27, Sect. 6
Solar Radiation	23e	SAI/LJ	27, Sect. 4
DSA System		GRC[a]	

[a]We have used a G.E. Tempo version.

7-2 GENERAL CODING INFORMATION FOR NBR MODULE

7-2.1 Routines in NBR Module

Table 7-2a lists all the (non-DSA) routines used in the NBR Module. Those routines from the DSA System [SP-78] we have used in the NBR Module are listed in Table 7-2b. In Table 7-2a, each of the routines is annotated by a letter, defined in the footnotes, which identifies either the module or a category to which it belongs.

7-2.2 Calling Structure of Routines

The essential relationships between all of the routines in the NBR Module are shown in Figure 7-1; however, we have omitted all the DSA routines except for QINITL which we include as a reminder that the DSA system is there. Calls to the left of the heavy vertical line are those required for inclusion of the statistical cloud submodel.

In addition to the routine names in Figure 7-1, we include annotations to enhance the utility of the diagram. Near the top of the figure, a dashed line divides the initializing calls from those made later while looping over the spectral bands. The T (for TRUE) besides the SUN-hexagon means the indicated call is made if the sun is present (above the horizon). Vectors $\vec{V}$, $\vec{P}$, $\vec{C}$, and $\vec{S}$, refer, respectively, to positions for (a) the (fictitious) viewing point at which the upwelling radiance is being calculated, (b) a representative point on the Earth's surface toward which the (fictitious) detector at Point V is pointed, (c) the intersection of the detector's line-of-sight with the 12-km altitude surface (the highest altitude of cloud tops), and (d) the sun. Vectors such as $\overrightarrow{PS}$ denote paths joining the indicated points. The indices I,J,K,M, and L are, respectively, those for altitudes, nadir angles, azimuth angles, broad-bands (from Dataset-BN), and band-intervals within a broad-band (from Dataset-BI). On the second and third pages of Figure 7-1, the indices I,J,K, and L head columns of entries which are either 1 or $\geq$ 1. Each row of such entires is correlated with the call to a routine (or a set of routines) on the same line. Such entries denote the values of the indices for which the call is made to achieve maximum economy.

Table 7-2a. Routines in the Natural Background Radiation (NBR) Module.

Routine	Comment*	Routine	Comment	Routine	Comment
ACCUM	T	GEOREA	X	SOLVE	A
AEROSOL	P	GEOTAN	X	SOLZEN	A
AGAGEO	X	GEOXYZ	X	SORTLJ	C
ATMOSU	A,C,T,E	GLITTR	E	SPCMIN	A
ATMRAD[c]	T	H2OSVP	A	STEP	T
BESSO	C	IONOSU	A	STEPS	T
BK CDATA	C	JULIAN	A	SUBVEC	T,V
CANGLE	E	LINEAR	C,E	SURPAD	E
CFLOSF	C	OZONE	A	TAIR	C
CLDBDR	C	PATH	T	TANGEO	X
CLDGEOM[a]	C	PLANCK	T,E	TEMPZH	A
CLDWT	C	RATCOF	A	TRANS	T
CLOUDO	C	REATAN	X	TRANSB[c]	T
DOT	T,V	RHOEPS	C	TRANSF	C
DRVUPW[c]	U	RINOUT	E	TRNSCO[c]	T
EMISSF	C	SEGMENT	T	UNITV	T,V
ERF	E	SETALT	U	UPWELL[c]	U
ESURF	E	SGEOM	C	VLIN	T,V
FITTER	A	SHELLS	T	WATER	A
FRAC	T	SOLCYC	A	WVOPT	A
FRESNL	E	SOLORB	A	XMIT[b]	T
GCRCLE	E	SOLRAD	S	ZTTOUT	A

A Routine from Ambient Atmosphere Module.

C Routine from Statistical Submodel of Natural Cloud Module.

E Routine from Earth Surface Characterization and Radiance Module.

P Routine from Atmospheric Aerosols Module.

S Routine from Solar Radiation Module.

T Routine from Atmospheric Thermal Emission and Molecular Transmittance Modules.

U Routine from Upwelling Natural Radiation Module.

V Routine for relations between vectors.

X Routine for transformation of coordinates.

a A dummy routine to simulate that from the Deterministic Submodel of the Natural Cloud Module which, though loaded to satisfy externals, is not otherwise used.

b This routine is a FORTRAN-language version, prepared by L. Ewing, of the COMPASS-language routine used in the GRC DSA System. Here, it is used independent of its role in the DSA System.

c Employs the DSA System.

Table 7-2b. Routines from the DSA System used in the NBR Module.

CREATE[p,a]	NEXT[p,b]	QCREAT	QGCBLK	QZBLOK
CREATX	NLOKDS	QDSRED	QGDBLK	REMOVE
DSPWRD[p]	PUTAFT	QDSRYT	QGRBAG	WIPOUT[p]
DSTROY[p]	PUTBOT[p,c]	QERROR	QGTZWD	XMIT[p]
INDWRD[p]	PUTORD[d]	QFIELD	QINITL[p]	
LOCKDS[p]	QCEASE	QFLDST	QPTZWD	

[p]Primary calls.

[a]Has entry point CREATL[p].

[b]Has entry points PREV[p] and PREVNL[p].

[c]Has entry point PUTTOP[p].

[d]Has entry point PUTORA[p].

7-2.3 Description of Routines: Function Performed, Originator, and Locations of Listing and Input-Output Table

In Table 7-3a, for all the (non-DSA) routines in the NBR Module (as listed in Table 7-2a), we provide a short description of the routine's function. We also identify (a) the organization (if not SAI) originating the routine, (b) the number of the volume in the ROSCOE Manual containing a listing of the routine, and (c) the number of the table in Volume 27 when we have summarized the inputs and outputs for the routine.

In Table 7-3b, we provide a short description of those DSA routines which are called directly from the NBR Module.

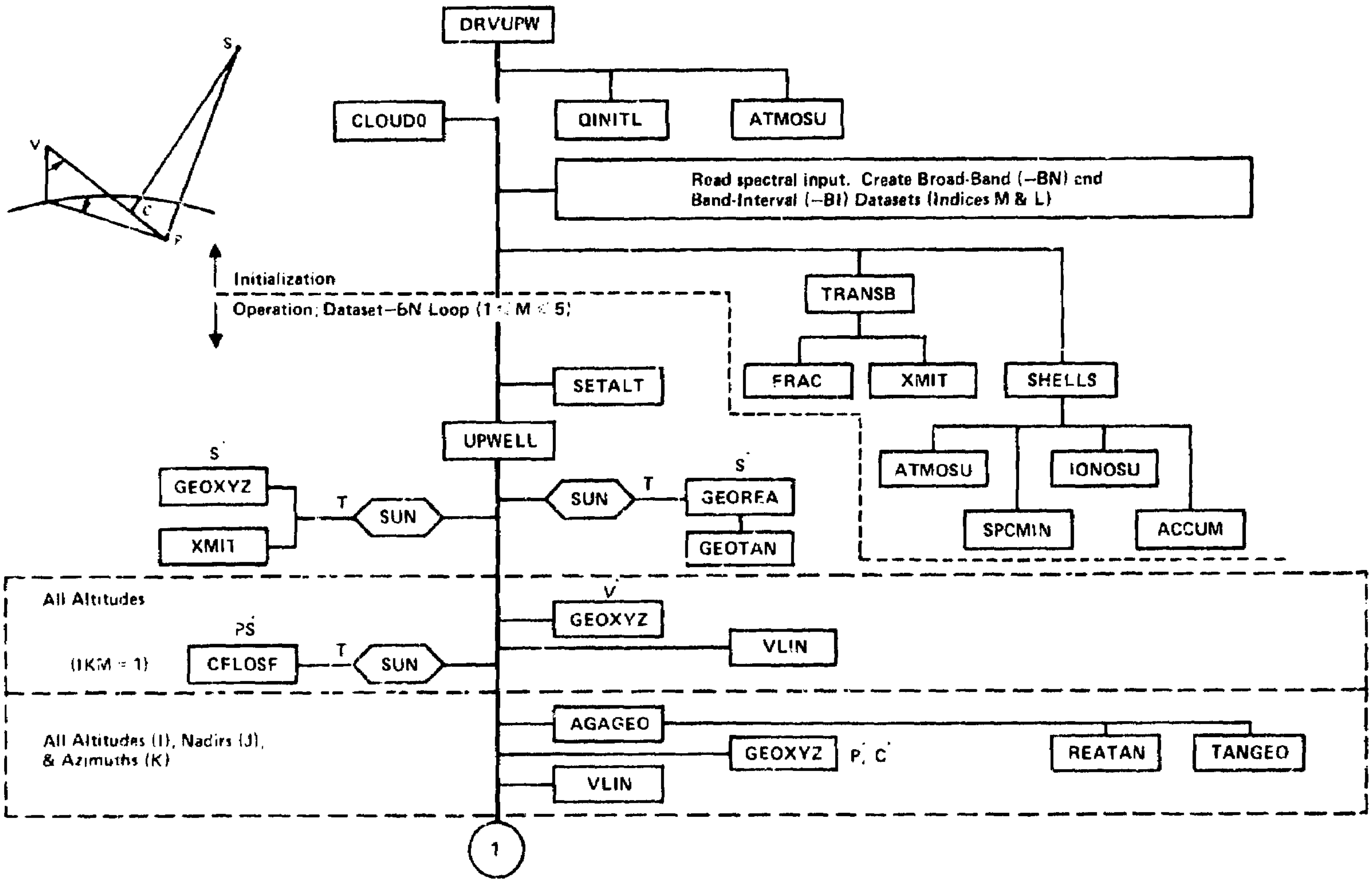


Figure 7–1. Relationships between the routines in the Natural Background Radiation Module.

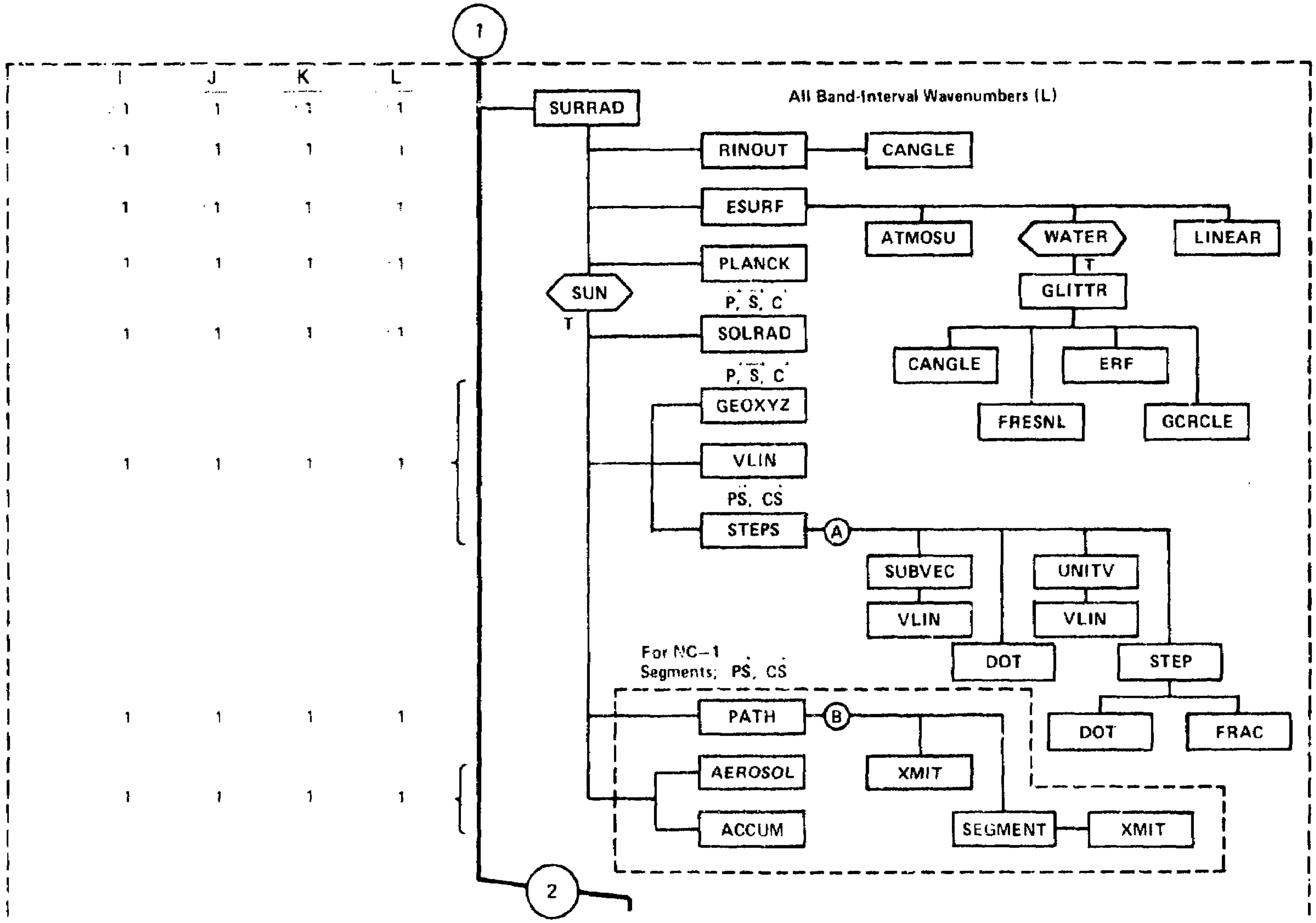


FIGURE 7-1. (CONTINUED)

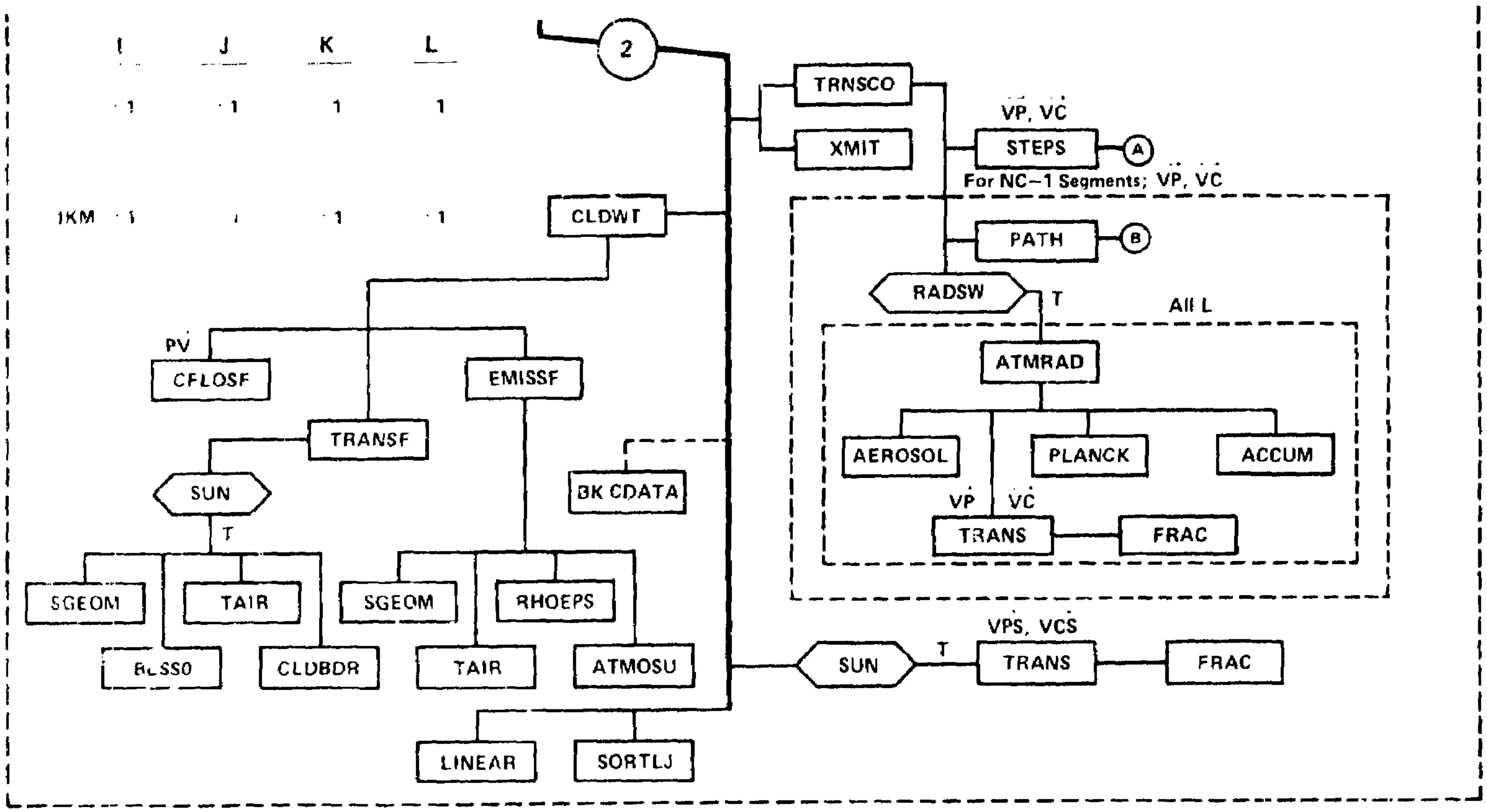


FIGURE 7–1. (CONTINUED)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table.

Routine	Function performed
ACCUM	Integrates (between X=A and X=B) a function F(X) given at two points X1 and X2, by using linear, logarithmic, or power-law interpolation, corresponding to specified ITYPE = 1,2,3, respectively; uses linear interpolation in case the other methods would fail. (GET routine; listing in Vol. 27.)
AEROSOL	Computes attenuation coefficients for scattering and absorption (and, though not used in the NBR Module, the asymmetry factor (average cosine of the scattering angle)) due to atmospheric aerosols, given the altitude and wavelength. (VI routine; see Vol. 25 for original routine which differs slightly from ours in Vol. 27. Input-output in Table 5-4.)
AGAGEO	Provides the geographic coordinates (colatitude and east longitude) of Point 2, given the geographic coordinates of Point 1, the azimuth and Earth-central angle of Point 2 with respect to Point 1, and the height of Point 2. (A modified MRC HARC routine; listing in Vol. 27. Input-output in Table 6-3.)
ATMOSU	Computes the properties of the undisturbed atmosphere, given the altitude (ZH), after the associated subroutines compute the local apparent time (HL), solar flux (SBAR), and day-or-night parameter (IDORN). (Listing in Vol. 14a-1.)
ATMRAD	Computes the atmospheric volume emission on an optical path. (GET routine; listing in Vol. 27. Input-output in Table 6-9.)
BESSO	Provides the zero-order cylindrical Bessel function per Formulas 9.4.1 and 9.4.3 in AS-54 (Listing in Vol. 24.)
BKDATA CDATA	Provides (1) for 14 cloud types, their (a) base altitude, (b) thickness, (c) water droplet radius, (d) water droplet density, and (e) optical scattering properties (extinction and scattering cross-sections and mean cosine of scattering angle) at 10 wave-lengths in the 2- to 5-μm range, and (2) for Regions 4 and 11 in the NASA cloud-data base, (a) the statistical-cloud index, (b) occurrence frequencies of cloud types, and (c) occurrence frequencies of number of cloud layers. (Listing in Vol. 24.)
CANGLE	Computes the Earth-central angle (CANGLE) between the two central rays to Points P1 and P2, given the north latitudes and east longitudes of Points P1 and P2. (Listing in Vol. 27. Input-output in Table 6-3.)

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

CFLOSF	Computes the probability of a cloud-free line-of-sight (CFLOS) as a function of the cloud coverage (expressed in tenths) and zenith angle of the LOS from the ground. (Listing in Vol. 24.)
CLDBDR	Provides the bidirectional reflectance (1/sr) of a plane, semi-infinite stratocumulous (KCLOUD=4) cloud for a photon of wavelength ALAM incident at zenith angle THIN = ACOS(CTHIN) and reflected at zenith angle THOUT = ACOS(CTHOUT) and azimuth angle PHIOUT = ACOS(CPHIOUT). (Listing in Vol. 24.) Known as ALBEDC in ROSCOE-IR.
CLDWT	Computes (for a given source and detector location) three arrays (TRANS, EMISS, and WT), each with IDX members (normally 160). The TRANS and EMISS arrays are, respectively, (1) the distribution of irradiance-to-radiance transfer coefficients (1/sr) at the 12-km altitude transfer point for clouds and (2) the distribution of (attenuated) spectral cloud-emission radiances at 12-km altitude and directed toward the detector. The WT array is the set of weights associated with the set of statistical cloud configurations, influenced by cloud-coverage fractions and cloud-free line-of-sights from the detector. (Listing in Vol. 24.)
CLOUDO	Reads (a) a flag (MODE) indicating by a value of 0 or 1 whether the deterministic- or statistical-cloud submodel is desired, (b) cloud data appropriate to the indicated submodel and makes them available to the appropriate routines. For MODE=1, the routine reads an index KMODEL which selects data from that in the code or allows the user to input his own data. Other flags are read which allow selected portions of the provided data to be overridden. These user-provided data are output through CLDFRQ and CONFIG Commons and override data in BLOCK DATA CDATA. (Listing in Vol. 24.)
DOT	Computes the dot product of two vectors. (GET, GRC routine; listing in Vol. 27.)
DRVUPW	Drives, and provides a means for testing, the NBR Module, by accepting the necessary input data for each of the modules (see Table 7-1) integrated into the NBR Module and printing selected results. (Listing in Vol. 27.)
EMISSF	Computes the (attenuated) spectral radiance at 12-km altitude for radiation emitted (at a specified zenith angle) from a cloud top at a specified altitude. (Listing in Vol. 24.)

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

ERF	Evaluates the error function, based on the rational-approximation Formula 7.1.2.6 in AS-64. (Listing in Vol. 27.)
ESURF	Provides the bidirectional reflectance-distribution function (BRDF), directional emissivity, and temperature of the Earth's surface at the intersection point of the optical line-of-sight with one of the seven allowed categories of surface materials. (The surface temperature is approximated by using the atmospheric-model temperature.) (Listing in Vol. 27. Input-output in Table 2-12.)
FITTER	Computes, by the method of least squares, the coefficients Z(J) (J=1,N) in a polynomial of degree N representing the dependent variable Y(I) (or, optionally, its natural logarithm) specified (and given equal weights) at NPTS values of the independent variable X(I). (Listing in Vol. 14a-1.)
FRAC	Computes the fraction of interval (A,B) either contained in interval (X,Y) if (A,B) $\leq$ (X,Y) or covered by interval (X,Y) if (A,B) > (X,Y). (GET routine; listing in Vol. 27.)
FRESNL	Evaluates the Fresnel (specular) monochromatic reflectance of a smooth water surface (characterized by a complex index of refraction), given the wavelength (in the 2- to 5-μm range) and angle of incidence. (Listing in Vol. 27. Input-output in Table 3-4.)
GCRCLE	Computes, for three Points P1, P2 and P3 on a great circle, the latitude and longitude of the intermediate point P2, given the latitudes and longitudes of the end points P1 and P3, the central angle ALP13 between the central rays to P1 and P3, and the central angle ALP12 between the central rays to P1 and P2. (Listing in Vol. 27. Input-output in Table 3-5.)
GEOREA	Provides the slant range, elevation angle, and azimuth angle of Point 2 with respect to Point 1, given the geographic coordinates (altitude, colatitude, and east longitude) of the two points. (A modified MRC HARC routine; listing in Vol. 27. Input-output in Table 6-4.)
GEOTAN	Provides the tangent-plane coordinates of Point 2 with respect to Point 1, given the geographic coordinates (altitude, colatitude, east longitude) of the two points. (A modified MRC HARC routine called GEOXYZ; listing in Vol. 27. Input-output in Table 6-5.)

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

GEOXYZ	Converts the geographic coordinates (altitude, north latitude, east longitude) of a point to Earth-centered Cartesian coordinates. (Listing in Vol. 27. Input-output in Table 5-3.)
GLITTR	Provides, upon being called from Subroutine ESURF when the line-of-sight intersects a water surface, (1a) the bidirectional reflectance-distribution function (BRDF) and (1b) directional emissivity of the water surface at the intersection point of the optical line-of-sight from the detector and (2) the geographic coordinates (north latitude and east longitude) of the point on a smooth horizontal surface for a specular reflection of a ray from the source to the detector, if requested (by logical parameter SPCULR=.TRUE. in argument list). Only the directional emissivity is provided if there is no source. (Listing in Vol. 27. Input-output in Table 3-2.)
H2OSVP	Computes the saturation vapor pressure of water vapor over a plane surface of (1) water for the temperature range from 173.15 to 373.15 deg K (-100 to +100 deg C) and (2) ice for the temperature range from 173.15 to 273.15 deg K (-100 to 0 deg C). (Listing in Vol. 14a-1.)
IONOSU	Provides the properties of the ambient ionosphere required by all the chemistry modules. (Listing in Vol. 14a-1.)
JULIAN	Converts a Gregorian calendar date to Julian day number DAYJ for Subroutine SOLORB. (Listing in Vol. 14a-1.)
LINEAR	Performs a linear interpolation to find FXO at a given XO, given the independent variable array XX(I) and the corresponding dependent variable array FXX(I). FXO is set to zero if XO is not within the range of XX(I). An efficient search is used. (Listing in Vol. 24.)
OZONE	Computes the latitude and season dependence of ozone for altitudes from 0- to 55-km. (For higher altitudes, see Subroutine SPCMIN.) (Listing in Vol. 14a-1.)
PATH	Develops the cumulative values of the path parameters U(I,N,2) (species-N areal density) and UP(I,N,2) (product of U and pressure P) for temperature-index I and species N at end of line segment DS(J+1), expressed, respectively, in cm at STP and atm-cm at STP (if Loschmidt's number is expressed in molecules/cm^3 at STP). Incremental values are obtained from Subroutine SEGMENT. (GET routine; listing in Vol. 27. Input-output in Table 5-5.)

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

PLANCK	Computes the blackbody spectral radiance. (GET routine; listing in Vol. 27. Input-output in Table 5-6.)
RATCOF	Provides the rate coefficients needed for the E- and F-region ionosphere model used in ROSCOE-IR. (Listing in Vol. 14a-1.)
REATAN	Provides the tangent-plane coordinates of a point with respect to some reference location, given the slant range elevation angle, and azimuth angle of the point with respect to the same reference location. (A modified MRC HARC routine called REAXYZ; listing in Vol. 27. Input-output in Table 6-6.)
RHOEPS	Computes the hemispherical-directional reflectance from the (horizontal) surface of cloud-type 4 (stratocumulous) for radiation of wavelength λ reflected into zenith angle ε. (Listing in Vol. 27.)
RINOUT	Computes - when given the geographic location (altitude, north latitude, east longitude) of the sources (sun and/or fireballs), the detector, and the position P of the intersection of the line-of-sight from the detector to the Earth's surface - the zenith angles and slant ranges of the sources from P and the direction of the ray from P toward the detector in terms of the zenith angle of the detector and (if the surface is not Lambertian (MAT=1) or water (MAT=2)) the absolute value of the azimuth angle of scatter with respect to the principal plane containing the incoming ray. (Listing in Vol. 27. Input-output in Table 5-2.)
SEGMENT	Computes the incremental values of the path parameters DU(I,N) and DUP(I,N), for temperature-index I and species N, for the line-segment DS, based on a linear variation of the properties in DS. Units are, respectively, cm at STP and atm-cm at STP (if Loschmidt's number is expressed in molecules/cm^3 at STP). Cumulative values are formed in Subroutine PATH. (GET routine; listing in Vol. 27. Input-output in Table 5-7.)
SETALT	Determines the altitudes at which Subroutine UPWELL computes the upwelling natural radiation. A set of characteristic altitudes has been previously selected for each of the 10 spectral bins spanning the 2- to 5-μm range. If the wavelength-band of interest (ALMIN, ALMAX) spans more than one bin, a set of altitudes is obtained by combining those for each of the spanned bins. (Listing in Vol. 27. Input-output in Table 7-7.)

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

SGEOM	Computes the geometrical relations between a source, (statistical) cloud layer, and detector. (Listing in Vol. 24.)
SHELLS	Prepares arrays of physical properties at spherical-shell boundaries used in calculating molecular transmittance through the ambient atmosphere. Properties at each shell-boundary are altitude, temperature, pressure, and number densities of species (CH_4, CO, CO_2, H_2O, NO, NO^+, NO_2, N_2O, O_3, and OH). For information, the water content of the atmosphere above each shell boundary is also computed, expressed in units of precipitable centimeters. (Modified GET routine; listing in Vol. 27. Input-output in Table 7-9.)
SOLCYC	Computes the solar flux (SBAR), an input to ATMOSU through ATMOUP Common, based on an assumed sinusoidal 11-year (or 4018-day) variation. with the maximum value of 250 for SBAR (associated with the CIRA-65 Model 9) occurring on 1 June 1958, 1 June 1969, 1 June 1980, etc. and with the minimum value of 65 for SBAR (associated with the CIRA-65 Model 1) occurring on 1 December 1963, 1 December 1974, 1 December 1985, etc. (Listing in Vol. 14a-1.)
SOLORB	Computes the north latitude (SOLLAT) and east longitude (SOLLON) of the apparent (actual motion) subsolar point, given the Julian day number at 0 hours UT on 1 January of the year of interest (YRFJ), the Julian date at which vernal equinox occurs (VEQJ), the Julian day number at 0 hours on the day of interest (DAYJ), and the universal time (UT). (Listing in Vol. 14a-1.)
SOLRAD	Provides the solar spectral irradiance at the top of the Earth's atmosphere, in the spectral range from 2- to 5-μm (or 5000- to 2000-wavenumbers). The NASA data adopted by the ASTM have been fitted by piecewise-continuous power-law expressions. (Listing in Vol. 27. Input-output in Table 4-2.)
SOLVE	Solves a set of N simultaneous linear algebraic equations by using the Gauss-Jordan method with maximum pivot feature. (Listing in Vol 14a-1.)
SOLZEN	Computes (1) the cosine of the zenith angle of the sun at a Point P (COSCHI), given the geographic north latitude (PLAT) and east longitude (PLON) of the Point P and the north latitude (SOLLAT) and east longitude (SOLLON) of the subsolar point, (2) the day-or-night parameter (IDORN), which is 1 if COSCHI $\geq$ 0.0 and 0 otherwise, and (3) the local apparent time (HL), from the Greenwich apparent time (GAT) and the longitude PLON. (Listing in Vol. 14a-1.)

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

SORTLJ	Sorts an array A of length N from low to high (if LOHI ≤ 0) or from high to low (if LOHI > 0). Two additional arrays are simply carried along in the sorting process. (Listing in Vol. 24 is adequate for use with Clouds Module but listing in Vol. 27 must be used for NBR Module.)
SPCMIN	Provides analytic-fit profiles at all altitudes of the minor species (N, NO, NO_2, O_3, $O_2(^1\Delta_g)$, and H_2O) not provided by Subroutine ATMOSU but needed by the chemistry modules, by using tabular data-base species-densities. For ROSCOE-IR, also provides for CO, N_2O, CH_4, H, OH, HO_2, $N(^2D)$, $N(^2P)$, and $O(^1D)$, as well as revised profiles of O_3, H_2O, N, $N(^4S)$, and NO. (Listing in Vol. 14a-1.)
STEP	Calculates the intersections of an optical path with the boundaries of the atmospheric shells determined in Subroutine SHELLS. Path elements less than 10 meters in length are assigned to the neighboring shell. The output includes (a) the number of path segments (plus one) on the transmission path, (b) the length of the path segment along the transmission path, (c) the weight associated with the Ith end point appropriate for finding at that point the linearly-interpolated value of the parameter, and (d) the index of the shell boundary at or just before the start of the line segment. (GET routine; listing in Vol. 27. Input-output in Table 5-8.)
STEPS	Serves effectively as an entry to Subroutine STEP, given the optical path defined by its end point vectors RX(I) and RY(I). (GET routine; listing in Vol. 27. Input-output in Table 5-9.)
SUBVEC	Returns the difference between vectors VX and VY, i.e., DVXY (1-3) = VX(1-3) - VY(1-3). (GET routine, equivalent to GRC routine with same name and argument list; listing in Vol. 27.)
SURRAD	Provides (essentially) the upwelling radiance directed toward the detector at the point where the optical line-of-sight intersects the Earth's surface. This version of SURRAD provides two components of the radiance: (1) thermally emitted and (2) source (sun or fireball) reflected. Reflected sky radiance is not included. Strictly, the source-reflected component is actually provided in an unattenuated form together with the path parameters (species areal density U and UP, with P the pressure), integrated along the incoming path from the source, required as input to a computation of the molecular absorption over a total

(continued)

Table 7-3a. Description of routines in . Module: function performed, originator, and locations of listing and input-output table (Cont'd).

	path. The aerosol transmittance along the incoming path from the source is also provided. The statistical cloud submodel is also included; see Subroutine UPWELL for comments. Note that the input parameters for Point C in POSITN Common and IKM in UPWELS Common facilitate providing, as additional outputs for the path from the sun to Point C at 12-km altitude, the path parameters UCS and UPCS and the aerosol transmittance TASC(LUP). (Listing in Vol. 27. Input-output in Table 5-1.)
TAIR	Provides, for use within the statistical-cloud submodel, the molecular transmittance for radiation of wavelength ALAM from altitude ALT to 12 km along a path at zenith angle THETA, by interpolating results from using the AFGL LOWTRAN-III code with the 1962 U.S. Standard Atmosphere. (Listing in Vol. 24.)
TANGEO	Provides the geographic coordinates of a Point 2, given the geographic coordinates of Point 1 and the tangent-plane coordinates of Point 2 with respect to Point 1 (called Subroutine XYZGEO in ROSCOE-Radar). (A modified MRC HARC routine called XYZGEO; listing in Vol. 27. Input-output in Table 6-7.)
TEMPZH	Determines the temperature profile (tabular, 0(4)120 km) by interpolating the data base (U.S. Standard, 1966) for latitude and season, to be used as input to the major atmospheric species model for the low-altitude range from 0- to 120-km altitude. (Listing in Vol. 14a-1.)
TRANS	Provides the molecular transmittance and optical depth for each of the ten species and the total molecular transmittance in a specified wavenumber interval, given the parameters U (cm at STP) and UP (atm-cm at STP) for the total transmission path. (GET routine; listing in Vol. 27. Input-output in Table 6-10.)
TRANSB	Processes the 5-cm^{-1} resolution band-model parameters file so as to (1) eliminate the data for the unwanted spectral regions and (2) derive new parameters with modified resolution in accordance with the user-setting of the logical variable TRNSOPT. The method for TRNSOPT set to .TRUE., for faster but less accurate calculations, provides in-band averaged band-model parameters. The method for TRANSOPT set to .FALSE., for slower but more accurate calculations, provides band-model parameters at a finer resolution, actually 0.5 of the narrowest user wavenumber band-interval, but within the range of 5 to 50 cm^{-1}. The two band-model parameters are (a) S(I,IS), the mean absorption coefficient

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

	for species-IS at temperature-index-I for the interval DW, cm^{-1} at STP, and (b) DE(I,IS), the inverse of mean line-spacing parameter, or the effective line density, lines/cm^{-1}. (GET routine; listing in Vol. 27. Input-output in Table 7-8.)
TRANSF	Computes a quantity defined in the natural statistical-cloud submodel as the irradiance-to-radiance transfer coefficient (1/sr) or simply the transfer coefficient at the intersection of the detector LOS vector with 12-km altitude (known as the transfer point). The transfer coefficient is actually the ratio of a radiance and an irradiance. The radiance is that directed antiparallel to the detector LOS vector and the irradiance is the (unattenuated) source irradiance at the transfer point. For a source above 12-km altitude and far from the transfer point (as for the sun), the transfer coefficient becomes essentially the bidirectional reflectance of the cloudtop times the cosine of the zenith angle of the incident ray. For a source below or within the clouds (conditions not allowed in NBR Module), the transfer coefficient depends on the details of the diffusion solution to the transport of radiation through the clouds. (Listing in Vol. 24.)
TRNSCO	Provides, for RADSW=.TRUE. as in the NBR Module, a call to Subroutine ATMRAD to evaluate Words-5, -7, and -8 of Dataset-BI (in-band-interval radiance, product of molecular and aerosol transmittance, and aerosol transmittance). (GET routine; listing in Vol. 27. Input-output in Table 6-8.)
UNITV	Returns the unit vector VXHAT(1-3) along the vector VX(1-3). (GET routine, equivalent to GRC routine with same name and argument list; listing in Vol. 27.)
UPWELL	Computes - for a Point V at each of a set of NALTJ altitudes above a given geographic position, specified in UPWELS Common (UPWALT, UPWLON, UPWLAT) and characterized by material MSM and property DD(MSM) - the natural upwelling spectral radiance directed towards Point V from Points P located on the Earth's surface with respect to Point V at NNADIR representative nadir angles and NAZI representative azimuth angles. This upwelling radiance, UPRAD(I,J,K,L), includes contributions from (1) air emission between Points V and P, (2) surface emission at Point P,

(continued)

Table 7-3a. Description of routines in NBR Module: function performed, originator, and locations of listing and input-output table (Cont'd).

	and (3) the solar-reflected radiation at each of the Points P. Values of the radiance UPRAD(I,J,K,L) are averaged over azimuth angles to give UPRADA(I,J,L) and over nadir angles to give UPRADN(I,L,JBAND). For inclusion of natural (statistical) clouds, distribution functions of the radiance are obtained instead of the single values in the absence of clouds. Selected percentiles (10, 25, 50, 90, 100) of the corresponding integral distributions are output. Note that for the GRC version of the NBR Module integrated into ROSCOE-IR, the array UPRADN(I,L,JBAND) (for altitudes ≥ 12 km and if clouds are included) is reset as UPRADN(I,L,JBAND) = RO50N (IKM,L) + ARCVN(IKM,L), which is transferred through UPWELS Common to (the GRC) Subroutine UPWELT. Thus, in the GRC version, for altitudes ZKM ≥ 12-km, UPRADN is not the cloud-free result but the 50-percentile of the radiance distribution function for statistical clouds (if included in the problem). (Listing in Vol. 27. Input-output in Table 6-2.)
VLIN	Returns the linear combination of two vectors, X(1-3) = A*Y(1-3) + B*Z(1-3). (GET routine, corresponds to GRC routine VECLIN with transposed arguments; listing in Vol.27.)
WATER	Computes the longitude, latitude, and season dependence of water vapor for altitudes from 0- to 45-km. (For higher altitudes, see Subroutine SPCMIN.) (Listing in Vol. 14a-1.)
WVOPT	Allows the user to bypass the normal treatment (achieved by setting WVFLAG = 0.0) of water vapor in Subroutine SPCMIN for the altitude range from 0 to 120 km. The user effects the bypass by reading in WVFLAG .GT. 0.0 and his own data in one of four optional forms according to METHOD = 1, 2, 3, 4. (Listing in Vol. 14a-1.)
XMIT	Returns an array Y copied from a given array X of length LX if LX > 0 and sets Y (of length |LX|) to a constant X(1) if LX < 0. (A COMPASS-language version of the routine is used with the GRC DSA system, though no listing of it is included in SP-78. We have used a FORTRAN version of the routine prepared by L. Ewing of G.E. Tempo. Listing in Vol. 27.)
ZTTOUT	Converts a Gregorian calendar date (expressed as 20th century year (IYRS), month (MONS), and day (IDAYS)) and zone time (ZT) at east longitude PLON to the Gregorian calendar date and mean time (UT) at Greenwich. (Listing in Vol. 14a-1.)

Table 7-3b. Description of Dynamic Storage Allocation routines called directly from the NBR Module.

Routine	Function Performed
CREATE	Creates a dataset of (at least) n+1 words and returns the dataset index (the pointer to the first (not zeroth) word of the dataset).
CREATL	Performs the same as in Subroutine CREATE, except that the dataset lock value and lock count are set to 1 (locked).
DSPWRD	Returns the pointer to the DSP word for the dataset specified by its index.
DSTROY	Returns to the system the space occupied by the dataset specified by its index.
INDWRD	Returns the index for the dataset specified by the pointer to its DSP word.
LOCKDS	Sets the specified lock number of the dataset specified by its index.
NEXT	Returns the link word and index for a dataset (in forward order) on a list, given initially the pointer to the list header and subsequently the previously-returned link word.
PREV	Returns the link word and index for a dataset (in backward order) on a list, given initially the pointer to the list header and subsequently the previously-returned link word.
PREVNL	Performs the same as Subroutine PREV, except that lock values are not set and reset.
PUTBOT	Places the dataset specified by its index as the bottom dataset on a list specified by its list-header pointer.
PUTORA	Inserts a dataset (specified by its index) into a list of datasets (specified by its list-header pointer) according to the ascending order of the specified nth words (with real values) of the datasets.
PUTTOP	Places the dataset specified by its index as the top dataset on a list specified by its list-header pointer.
QINITL	Initializes the routines in the DSA System.
WIPOUT	Removes all the datasets from the list specified by its list-header pointer and, if the parameter kdstry=1, also destroys the datasets.

7-2.4 Routines, Common Blocks, and Common-Block Variables

7-2.4.1 Routines and Common Blocks

In Table 7-4 we provide a matrix which shows the appearance of common blocks in the routines in the NBR Module.

7-2.4.2 Definitions of Common-Block Variables

In this section we either define the variables in a common block or give a reference where the definitions can be found. We also comment on the use of the common block and/or of its variables.

Blank COMMON

Blank COMMON is used only for the DSA System. For definitions of variables, see SP-78.

Common /AEROK/ KVIS, KPTYPE

The variables KVIS and KPTYPE are read in Program DRVUPW and transferred through /AEROK/ to Subroutine AEROSOL.

KVIS - Visibility range parameter (VR) for $0 \leq HCM \leq 9 \times 10^5$ cm
- =1, VR = 50 km
- =2, VR = 23 km
- =3, VR - 10 km
- =4, VR = 5 km
- =5, VR = 2 km

KPTYPE - Terrain parameter for $0 \leq HCM \leq 2 \times 10^5$ cm
- =1, Terrain is rural
- =2, Terrain is urban
- =3, Terrain is maritime

Common /AIRSOL/ TASP(10), TASC(10), TAFP(10)

The arrays TASP and TASC are set in Subroutine SURRAD and transferred through /AIRSOL/ to Subroutine UPWELL. (The array TAFP was never intended for

Table 7-4. Matrix of routines and common blocks.

Routine \ Common Block	Blank	AEROK	AIRSOL	ALTODN	ATMOUP	CODATA	CLDFREQ	CLDWT	CLOUD	CONFIG	DIFFUS	FIRBAL	FLAGS	IONOUP	OPTION	OPTIN1	PARAMS	POSITN	QNCNC	SANDD	SATELL	SOLARP	SORCE	SOURCE	TECTOR	TIME	UPWELS	UPWELS1	UPWELS2	UPWELS3	VPC	XY	XYZCOM	ZHCHEX	ZHTEMP
AEROSOL		X																																	
ATMOSU				X	X																	X				X								X	X
ATMRAD	X														X																		X		
BKCDATA						X	X																												
CLOBDR						X																													
CLDWT							X	X		X																									
CLOUD0							X		X	X							X																		
DRVUPW	X	X													X	X	X									X	X	X		X	X	X	X		X
EMISSF					X	X											X			X															
ESURF					X													X																	
GLITTR																		X						X	X										
IONOSU				X	X									X																				X	
JULIAN																										X									
OZONE					X																					X									
PATH																																	X		
QINITL	X																																		
RINOUT												X						X			X	X		X	X										
SEGMENT																																X			
SETALT																											X	X*							
SGEOM																	X																		
SHELLS					X																												X		
SOLCYC					X																														
SOLORB																										X									
SOLZEN					X																					X									
SPCMIN				X	X																					X					X			X	
SURRAD			X									X						X			X	X		X	X		X	X*	X	X*			X		
STEP																																	X		
TEMPZH																										X									X
TRANS																																X	X		
TRANSB	X														X																		X		
TRANSF						X					X		X				X			X			X												
TRNSCO	X														X				X														X		
UPWELL	X		X				X	X					X		X	X		X	X	X		X	X		X		X	X	X	X			X		
WATER					X																					X									
WVOPT					X																										X				
ZTTOUT																										X									

*Could be deleted.

use with the NBR Module but was provided should Subroutine SURRAD be used as a utility routine; this use has not evolved in ROSCOE-IR.)

For LUP=1,NWAVE(JBAND)

TASP(LUP), TASC(LUP) - Aerosol transmittance for incoming solar rays to Points P on Earth's surface and Point C at 12-km altitude on the VP-path. (Dimensionless; depends only on wavelength and assumed single paths.)

For L=1,IFIRES (not in NBR Module)

TAFP(L) - Aerosol transmittance for incoming ray from Fireball-L to Point P on Earth's surface. (Not used in ROSCOE-IR.)

Common /ALTODN/

Variables in /ALTODN/, defined in Subroutines ATMOSU and SPCMIN in Vol. 14a-1, are of no direct interest for the NBR Module per se.

Common /ATMOUP/ HL, SBAR, IDORN, PP, RHO, TT, SNI(30), HRHO, FEHSEQ

HL - Local apparent time (set by Subroutine SOLZEN). (decimal hours)

SBAR - Average 10.7-cm solar flux (set by Subroutine SOLCYC). [1.0E-22/(m^2 Hz)]

IDORN - Diurnal parameter (set by Subroutine SOLZEN).
=1, for daytime
=-1, for nighttime

PP - Pressure (set by Subroutine ATMOSU). (dyne/cm^2)

RHO - Mass density (set by Subroutine ATMOSU). (g/cm^3)

TT - Temperature (set by Subroutine ATMOSU). (deg K)

SNI(I) - Species-I density. (1/cm^3). The full array is defined in Subroutine ATMOSU. See Table 7-9 for those species used in computing the molecular transmittance.

HRHO - Density scale height (set by Subroutine ATMOSU). (km)

FEHSEQ - Fractional error in hydrostatic equilibrium (set by Subroutine ATMOSU).

Common /CDDATA/

The variables in /CDDATA/ are defined on p. 74 of Volume 24.

Common /CLDFREQ/

The variables in /CLDFREQ/ are defined on pp. 74, 75 of Volume 24.

Common /CLDWT/

The variables in /CLDWT/ are defined on p. 76 of Volume 24.

Common /CLOUD/

The variables in /CLOUD/ are defined on pp. 76, 77 of Volume 24. However, they are used only in the deterministic cloud submodel and hence are not used in the NBR Module.

Common /CONFIG/

The variables in /CONFIG/ are defined on p. 77 of Volume 24.

Common /DIFFUS/

The variables in /DIFFUS/ are defined on p. 78 of Volume 24; however, they are not used in the NBR Module.

Common /FIRBAL/ FBLAT(10), FBLON(10), FBALT(10), FBRINT(10)

/FIRBAL/ appears in two routines (RINOUT and SURRAD) even though the NBR Module does not use any of its variables. The reason for the appearance of /FIRBAL/ is that Subroutine SURRAD was created with a dual purpose in mind:

(1) As an integral part of the NBR Module, to be called from Subroutine UPWELL with only the sun as a source.

(2) As a utility routine, to be called by routines (other than UPWELL) needing the surface radiance (thermally emitted and source (sun or fireball) reflected). For such use, /FIRBAL/ was included.

However, Subroutine SURRAD is not used as a utility routine in ROSCOE-IR.

FBALT(L), FBLAT(L), FBLON(L) - Altitude, north latitude, and east longitude of Fireball-L. (km, radians, radians)

FBRINT(L) - Radiant intensity of Fireball-L. (W/sec)

Common /FLAGS/ ITFLAG

In order that Subroutine TRANSF in the Natural Cloud Module, called by Subroutine CLDWT, will know whether or not the sun is above or below the horizon, we require Subroutine UPWELL to set ITFLAG in /FLAGS/ before calling Subroutine CLDWT.

ITFLAG	-	Flag indicating the diurnal condition at Point V'. =0, Sun is below the horizon =1, Sun is above the horizon

Common /IONOUP/

The variables in /IONOUP/ are defined on pp. 133, 134 of Volume 14a-1; however, they are not used in the NBR Module.

Common /OPTION/ TRNSOPT

See TRNSOPT in Table 7-8 for Subroutine TRANSB, FAST in Table 6-10 for Subroutine TRANS, and TRNSOPT in Table 6-2 for Subroutine UPWELL.

Common /OPTIN1/ RADSW

See RADSW in Table 6-2 for Subroutine UPWELL and Table 6-8 for Subroutine TRNSCO.

Common /PARAMS/

/PARAMS/ contains constants used in the Natural Cloud Module. They are defined on p. 80 of Volume 24 and are set in Program DRVUPW.

Common /POSITN/ POSLAT, POSLON, POSALT, SPCLAT, SPCLON, C12ALT, C12LON, C12ALT

POSALT, POSLAT, POSLON	-	Altitude, north latitude, and east longitude of Point P at which line-of-sight (from fictitious detector at Point V) intersects Earth's surface. Set in Subroutine UPWELL. (km, radians, radians)
SPCLAT, SPCLON	-	North latitude and east longitude of the point on an assumed smooth horizontal surface for a specular reflection from the source to the detector at Point V. (Set in Subroutine GLITTR if SPCULR=.TRUE..) (radians)
C12ALT, C12LAT, C12LON	-	Altitude, north latitude, and east longitude of Point C at which line-of-sight (directed toward Point P from fictitious detector at Point V), intersects the 12-km

altitude surface. Set in Subroutine JPWELL. (km, radians, radians)

Common /QNCNC/ NCNC

See NCNC in either Table 6-2 for Subroutine JPWELL or Table 6-3 for Subroutine TRNSCO.

Common /SANDD/ XS, YS, ZS, XD, YD, ZD, UL, VL, WL

By calls to Subroutine GEOXYZ, Subroutine JPWELL sets - for use in Subroutine SGEOM after transfer from Function TRANSF in the Natural Cloud Module - the Earth-centered Cartesian coordinates of the sun (XS, YS, ZS) and of the fictitious detector (XD, YD, ZD) at Point V; the solar coordinates are zeroed if the sun is below the horizon. JPWELL also sets the direction cosines (UL, VL, WL) of Point P as viewed from Point V.

- XS, YS, ZS - Cartesian coordinates of the source location in the Earth-centered system. The x-direction points to zero degrees longitude and ninety degrees colatitude. The z-direction is through the north pole. (km)
- XD, YD, ZD - Cartesian coordinates of the detector location in the Earth-centered system. (km)
- UL, VL, WL - Direction cosines of the line-of-sight vector in the Earth-centered system.

Common /SATELL/ SATLAT, SATLON, SATALT, SATZEN, SATAZI

SATELL is not used in the NBR Module because Subroutine JPWELL does not deal with real sensors. /SATELL/ was included in Subroutine SURRAD on the assumption that it would be a utility routine, used when a real sensor in a satellite looks at the ground. However, SURRAD is not so used.

- SATALT, SATLAT, SATLON - Altitude, north latitude, and east longitude of satellite-borne detector. (km, radians, radians)
- SATZEN - Zenith angle of ray reflected at Point P towards the satellite. (Not computed.) (radians)
- SATAZI - Absolute value of azimuth of reflected ray, measured from principal plane determined by vertical plane

through incoming ray from sun. (Not computed.)
(radians)

Common /SOLARP/ SOLLAT, SOLLON, SOLIRR(1J)

The position variables, set in Subroutine ATMOSU after it calls Subroutine SOLORB during the initialization phase, are used in Subroutine UPWELL, SURRAD, and RINOUT. The irradiance, set in Subroutine SURRAD after it calls Subroutine SOLRAD, is used in Subroutines SURRAD and UPWELL.

SOLLAT, SOLLON	-	North latitude and east longitude of subsolar point. (radians)
SOLIRR(L) L=1,NWAVEJ	-	Solar spectral irradiance at the top of the atmosphere at wavenumber-index L. [W/(cm^2 cm^{-1})]

Common /SORCE/ NSORCE, HSORCE(1), RSORCE(1), THETAS, PHIS

The geometrical variables in /SORCE/ are set by Subroutine UPWELL in terms of the solar position (the only source with which Subroutine UPWELL is concerned) and are passed to Function TRANSF in the Natural Cloud Module.

NSORCE	-	The number of sources. Set to 1 in data statement in Subroutine UPWELL.
HSORCE(1)	-	Altitude of sun (RSUN). RSUN is set in data statement in Subroutine UPWELL. (km)
RSORCE(1)	-	Radius of source. True value for sun is not relevant for applications in NBR Module. Set to 0.0 in data statement in Subroutine UPWELL.
THETAS, PHIS	-	Colatitude and east longitude of subsolar point. (degrees)

Common /SOURCE/ SRCLAT, SRCLON, SRCALT, SRCFLG, SRCZEN(11), SRCSR(11)

The geometrical variables in /SOURCE/ are set by Subroutine RINOUT. Currently (April 1980) only the sun is used as a source for Subroutine SURRAD. (Fireballs are never used in the call to Subroutine SURRAD from Subroutine UPWELL in the NBR Module.)

SRCALT	-	Altitude of source if not the sun. (km)
SRCLAT, SRCLON	-	North latitude and east longitude of source (sun or fireball). (radians)

SRCFLG - Flag characterizing source
=1, Source is sun
=2, Source is fireball

SRCZEN(1) - Zenith angle of ray incoming to Point P from the sun. (radians)

For L=1,IFIRES (Not used in NBR Module)

SRCZEN(L+1) - Zenith angle of ray incoming to Point P from Fireball-L. (radians)

SRCSR(1) - Not defined.

SRCSR(L+1) - Slant range from Fireball-L to Point P. (km)

Common /TECTOR/ DETLAT, DETLON, DETALT, DETZEN, DETAZI(11)

Subroutine UPWELL uses /TECTOR/ to position a fictitious detector at Point V and pass the information to Subroutines SURRAD, RINOUT, and GLITTR. The scattering angles are set in Subroutine RINOUT and used in Subroutine SURRAD.

DETALT, DETLAT, DETLON - Altitude, north latitude, and east longitude of fictitious detector at Point V. (km, radians, radians)

DETZEN - Zenith angle of ray reflected at Point P on Earth's surface toward the detector at Point V. (radians)

DETAZI(1) - Absolute value of azimuth angle of reflected ray, measured from principal plane determined by vertical plane through incoming solar ray. (radians)

For L=1,IFIRE (Not used in NBR Module)

DETAZI(L+1) - Absolute value of azimuth angle of reflected ray, measured from principal plane determined by vertical plane through incoming ray from fireball. (radians)

Common /TIME/ IYRS, IMONS, IDAYS, ZT, PLAT, PLON, UT, GAT, FYR, FST, RHO5KM, CHI

The variables IYRS, IMONS, IDAYS, and ZT are read by Program DRVUPW. GCO and GLO are also read, in terms of which PLAT and PLON are set. UT is set by Subroutine ZTTOUT, GAT by Subroutine SOLORB, FYR and FST by Subroutine JULIAN, RHO5KM by Subroutine ATMOSU, and CHI by Subroutine SOLZEN.

IYRS - Number of the year in the 1900's at east longitude GLO (e.g., 1980 becomes 80).

IMONS - Number of the month at east longitude GLO (e.g., February becomes 2).

IDAYS - Day of the month at east longitude GLO.

ZT - Zone time for the 15-degree longitude interval containing east longitude GLO. (decimal hours)

GCO, GLO - Geographic colatitude and east longitude of grid origin or whatever reference point is desired. (degrees)

PLAT, PLON - North latitude and east longitude of grid origin. (radians)

UT - Universal time corresonding to zone time ZT. (decimal hours)

GAT - Greenwich apparent time. (decimal hours)

FYR - Fractional season-year, being zero on 1 January in the northern hemisphere and zero on 1 July in the southern hemisphere.

FST - Fractional summer, being one on 1 July and zero on 1 January in the northern hemisphere and reversed in the southern hemisphere.

RHO5KM - Mass density of dry air at 5-km altitude. (g/cm^3)

CHI - Zenith angle of the sun at grid origin. (radians)

Common /UPWELS/ UPWALT, UPWLON, UPWLAT, NALT(5), ZKM(13,5), NNADIR, NAZI, NWAVE(5), IDAYV, CLDFLG, UPRADN(13,10,5), WV(10,5), IKM, NBANDS

Program DRVUPW sets the variables UPWALT, UPWLON, UPWLAT, and NBANDS and the array NWAVE(M) (M=JBAND=1,NBANDS) and reads the variables NNADIR, NAZI, and CLDFLG. Program DRVUPW's call to Subroutine SETALT sets the arrays NALT(M) and ZKM(I,M) (M=1,NBANDS; I=1,NALT(M)). The call to Subroutine UPWELL sets IDAYV, UPRADN(I,L,M) (for I=1,NALT(M); L=1,NWAVE(M); M=1,NBANDS), and IKM.

The array WV(L,M) (L=1,NWAVE(M); M=1,NBANDS) is not used in the stand-alone version of the NBR Module but is set in Program (OOK in ROSCOE-IR to record the group of central wavenumbers of the band-intervals used in calling Subroutine UPWELL for each broad-band M.

UPWALT - Surface altitude of the sub-V-point. (km)

UPWALT, UPWLON - North latitude and east longitude of Point V at which upwelling radiance is computed. (radians)

For I=1,NALT(M); L=1,NWAVE(M); M=1,NBANDS

NALT(M) - Number of altitudes ZKM(I,M) for (broad) wavelength-band index M. Defines NALTJ.

ZKM(I,M) - Altitudes of Point V above UPWALT at which upwelling radiance is computed. (km)

NNADIR, NAZI - Number of nadir and azimuth angles at Point V at which upwelling radiance is computed.

NWAVE(M) - Number of wavenumbers at which the upwelling spectral radiance is to be computed for (broad) wavelength-band index M. Defines NWAVEJ.

IDAYV - Index for diurnal condition at sub-V-point.
=0, Solar zenith angle > 90 degrees
=1, Solar zenith angle ≤ 90 degrees

CLDFLG - Index for inclusion of natural clouds.
=0., Natural clouds are not included
=1., Natural clouds are included

UPRADN(I,L,M) - The nadir-averaged value of UPRADA(I,J,L). [W/(cm^2 sr cm^{-1})]

WV(L,M) - The array of central wavenumbers corresponding to (broad) wavelength-band index M. (Not used in stand-alone version of the NBR Module. Set in Program OLOOK and used in Subroutine UPWELT.) (cm^{-1})

IKM - Index for number of altitudes at which calculations are made when clouds are included. Used in Subroutines SURRAD and UPWELL.

NBANDS - Number of (broad) wavelength bands.

Common / UPWELS1/ R010(6,10), R010A(6,10,10), R010N(6,10),
R025(6,10), R025A(6,10,10), R025N(6,10),
R050(6,10), R050A(6,10,10), R050N(6,10),
R090(6,10), R090A(6,10,10), R090N(6,10),
R100(6,10), R100A(6,10,10), R100N(6,10)

Each of the arrays in /UPWELS1/ is computed in Subroutine UPWELL.

For XXX=10,25,50,90,100; IKM ≥ 1;

J=1,NNADIR; K=1,NAZI; L=1,NWAVE(M)

RXXX(K,L) - XXX-percentile of the integral distribution of the total (including that from statistical clouds) natural upwelling spectral radiance received at Point V for wavenumber-L (at implicit altitude-IKM above surface material MSM) along a ray directed to Point P on Earth's surface (at implicit nadir-J and explicit azimuth-K). [W/(cm^2 sr cm^{-1})]
Note: RXXX(K,L) does not include ARCVA(IKM,J,L). Currently, UPRAD(K,L) and RXXX(K,L) are being written in binary form on Logical Unit No. 8, for all appropriate altitudes and nadirs.

RXXXA(IKM,J,L) - The azimuth-averaged value of RXXX(K,L). [W/(cm^2 sr cm^{-1})]

RXXXN(IKM,L) - The nadir-averaged value of RXXXA(IKM,J,L). [W/(cm^2 sr cm^{-1})]

ARCVA(IKM,J,L) - When clouds are considered, a component of the upwelling spectral radiance received at Point V (at altitude-IKM), from air emission above 12-km altitude, along a ray directed to Point P on the Earth's surface (at nadir-J and independent of azimuth-K). [W/(cm^2 sr cm^{-1})]

ARCVN(IKM,L) - The nadir-averaged value of ARCVA(IKM,J,L). [W/cm^2 sr cm^{-1})]

Common /UPWELS2/ JBAND1

The variable JBAND1 is set to the (broad) wavelength-band index JBAND in Subroutine UPWELL and passed through /UPWELS2/ To Subroutine SURRAD to facilitate some print.

Common /UPWELS3/ UPRAD(6,10), UPRADA(13,10,10)

Both of the arrays in /UPWELS3/ are computed in Subroutine UPWELL. (As the code has developed, there remains little reason for including the array UPRAD in /UPWELS3/.

For I=1,NALT(M); J=1,NNADIR; K=1,NAZI; L=1,NWAVE(M)

UPRAD(K,L) - Natural upwelling spectral radiance received at Point V (at altitude-I above surface material MSM) along a ray directed to Point P on Earth's surface (at nadir-J and azimuth-K). I- and J-dependence is not stored, so user must print UPRAD(K,L) immediately after computation if he wants to see them. Currently, UPRAD(K,L) and RXXX(K,L) are being written in binary form on Logical

Unit No. 8, for all appropriate altitudes and nadirs. [W/(cm^2 sr cm^{-1})]

UPRADA(I,J,L) - The azimuth-averaged value of UPRAD(K,L). [W/(cm^2 sr cm^{-1})]

Common /VPC/ WVFLAG, METHOD

Currently, in Program DRVUPW, we set WVFLAG=0.0 and METHOD=0.

WVFLAG - Flag for optional treatment of water vapor.
= 0.0, Normal treatment
≠ 0.0, Optional treatment

METHOD - Flag indicating one of four options for treatment of water vapor.
=1, Data values in parts per million by mass. (ppmm)
=2, Data values in absolute humidity. (g/m^3)
=3, Data values in relative humidity. (percent; 10 percent is input as 10.0, not 0.10)
=4, Data values in dew-point temperature. (deg K)

Common /XY/ TT(10)

TT(I) - Temperature array in atmospheric transmission model. Set as data in Program DRVUPW and used in Subroutines SEGMENT and TRANS.

Common /XYZCOM/ ITMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81), XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS, FACT

The variables ITMTE, LTMTE, and NMOLS are set, and the variable FACT is read, by Program DRVUPW. Subroutine SHELLS sets the variable NS and the arrays HSHELL(81), TS(81), PS(81), and XNSPEC(81,10). Cumulative values of the path-parameter arrays U(10,10,2) and UP(10,10,2) are set by Subroutine PATH and used by Subroutine TRANS to compute the molecular transmittance.

ITMTE, LTMTE - Auxiliary input and output data file numbers for Subroutine TRANSB. Set to 2 and 3, respectively, in Program DRVUPW. See TAPIN and TAPOT in Table 7-8 for Subroutine TRANSB for more information.

NS - Number of boundary altitudes used in Subroutine SHELLS.

For J=1,NS
HSHELL(J), TS(J), PS(J), XNSPEC(J) - Altitude, temperature, pressure, and species-N density at altitude-boundary J. (cm, deg K, atm, cm^{-3})

For I=1,2 (adequate for ambient atmosphere); N=1,10

U(I,N,2) - Cumulative value of path parameters U (species-N areal
UP(I,N,2)   density) and UP (product of U and pressure P) for temperature-index I and species-N. See Table 5-5 for Subroutine PATH and Table 6-10 for Subroutine TRANS. (cm at STP, atm-cm at STP)

NMOLS - Number of species. Set in Program DRVUPW and used in Subroutines ATMRAD and TRANS (where known as NSPEC).

FACT - Parameter controlling the number of altitude boundaries and their spacing. See Table 7-9 for Subroutine SHELLS for more information.

Common /ZHCHEX/ ZHFLAG, SPIFLG

The variables in /ZHCHEX/ are defined and their use (to insure Subroutine ATMOSU is called prior to Subroutines IONOSU and SPCMIN) is described in the listings of Subroutines ATMOSU, IONOSU, and SPCMIN in Volume 14a-1. /ZHCHEX/ does not affect the NBR Module per se.

Common /ZHTEMP/ NZHT, ZHT(31), TZH(31), TPFLAG

For steps required by the user to bypass the code's specification of the temperature profile in the low-altitude (0- to 120-km) region, see p. 38 in Volume 14a-1. (The arrays ZHTZ(3) and TZHZ(3) appearing as arrays in /ZHTEMP/ in Volume 14a-1 are development artifacts and should be deleted.) Currently, in Program DRVUPW, we set TPFLAG=0.0.

NZHT - Number of altitudes (31) at which the low-altitude temperature profile is defined.

For I=1,NZHT

ZHT(I) - Altitudes at which the temperature profile is defined. =0.0(4.0)120.0 km

TZH(I) - Temperature profile (for TPFLAG=0.0), determined by interpolation of the data base [US-66] for latitude and season, used as input to the major atmospheric species model for the low-altitude range from 0- to 120-km altitude. (deg K)

- Temperature profile (for TPFLAG ≠ 0.0), specified by user at altitudes z = 0(4)120 km. (deg K)

TPFLAG - Flag for optional treatment of temperature profile.
= 0.0, Normal treatment

$\neq 0.0$, Optional treatment, allowing Subroutine TEMPZH to read the user-specified profile at altitudes z = 0(4)120 km

7-3 DRIVER PROGRAM DRVUPW AND INITIALIZING ROUTINES

7-3.1 Calculational Steps in Program DRVUPW

Here we describe the calculational steps required in the driver for the NBR Module, Program DRVUPW.

A. Initialization
  1. DSA System
     a. Set parameters
     b. Call QINITL
  2. Ambient atmosphere
     a. Read time and place
     b. Set option parameters for water vapor and temperature profiles
     c. Call ATMOSU
  3. Natural clouds
     a. Read/set parameters
     b. Call CLOUDO
  4. Create Datasets-BN and -BI
     a. Read spectral data
     b. Call CREATE, PUTBOT, or PUTTOP
  5. Compute band-model parameters
     a. Set option
     b. Call TRANSB
  6. Atmospheric shells
     a. Read/set option
     b. Call SHELLS
  7. Prepare to call UPWELL
     a. Read/set aerosol parameters

b. Read/set atmospheric emission option and transmittance parameter

c. Read/set geometry parameters for UPWELL

d. Read/set surface material parameters

B. Operation

1. Initiate (broad) wavelength-band spectral loop
2. Get Datasets
   a. Call PREV for Dataset-BN
   b. Call PREV for Dataset-BI
3. Set altitudes for UPWELL
   a. Set (broad) wavelength-band limits
   b. Call SETALT
4. Call UPWELL
5. Write results

7-3.2 Subroutine SETALT

The purpose of Subroutine SETALT is to provide a set of altitudes at which Subroutine UPWELL, for a given spectral range, will compute the upwelling natural radiation. To minimize the number of such altitudes, we have accounted for the spectral dependence of the air transmittance, as now described.

Our approach in selecting altitudes was to compute the upwelling radiance for a strictly nadir-looking sensor as a function of altitude and wavelength in the 2- to 5-μm band. The wavelengths used are the 27 test values given in Table 7-5. The resolution was 10 cm^{-1}. The altitudes used are 0(0.1)1(1)10(2)20(5)30(10)100 km. We used an atmosphere (see Volume 14a-1) or a zone time of 0.0 hours on 19 September 1978 at a geographic location of 45-deg north latitude, 0-deg longitude. The version of the code available at the time required the surface temperature to be independently specified. It was set at 288 deg K (instead of the air temperature at the first shell boundary which was 286.6-deg K). The surface emissivity was 0.9. The zoning of the atmosphere into shells was determined by FACT=1, but the algorithm used was not the one currently set by GRC (see Table 7-9 for Subroutine

SHELLS) but the one originally specified by G.E. Tempo, according to which the 76 shell thicknesses were 0.5263 km between 0 and 20 km and 2.105 km from 20 to 100 km.

Table 7-5. Wavelengths used in developing Subroutine SETALT.

Bin No.	Wavelength, μm: Bin Edge	Test Values	Bin Edge
1	2.0	2.0	2.1
2	2.1	2.40, 2.50, 2.55	2.575
3	2.575	2.60, 2.65	2.675
4	2.675	2.70	2.725
5	2.725	2.75, 2.80, 2.85	2.825
6	2.875	2.90, 2.95, 3.00, 3.20, 3.50, 4.00, 4.10	4.15
7	4.15	4.20, 4.25, 4.30, 4.40, 4.50	4.55
8	4.55	4.60, 4.70	4.75
9	4.75	4.80	4.85
10	4.85	4.90, 5.00	5.0

The results for these upward-vertical radiance calculations are shown in Figures 7-2a, 7-2b, and 7-2c for the 27 wavelengths. (The peaks at 50-km altitude for the strongly attenuated wavelengths simply reflect a peak in the atmospheric temperature profile at that altitude.) Examination of these curves led us to set the bin altitudes given in Table 7-6. More detailed work may indicate a need for revising the bin edges and/or altitudes. Subroutine SETALT is designed so that if the wavelength band of interest spans more than one bin, a set of altitudes is provided by combining those for each of the spanned bins. Table 7-7 gives the input and output variables for Subroutine SETALT.

The results in Figures 7-2a, 7-2b, and 7-2c are replotted in Figure 7-3 to show the spectral dependence of the upwelling radiance for a nadir-looking sensor, for altitudes of 0, 5, and 50 km. The curve for 0-km altitude is, of course, just that given by the Planck function for T=288 deg K and an emissivity of 0.9.

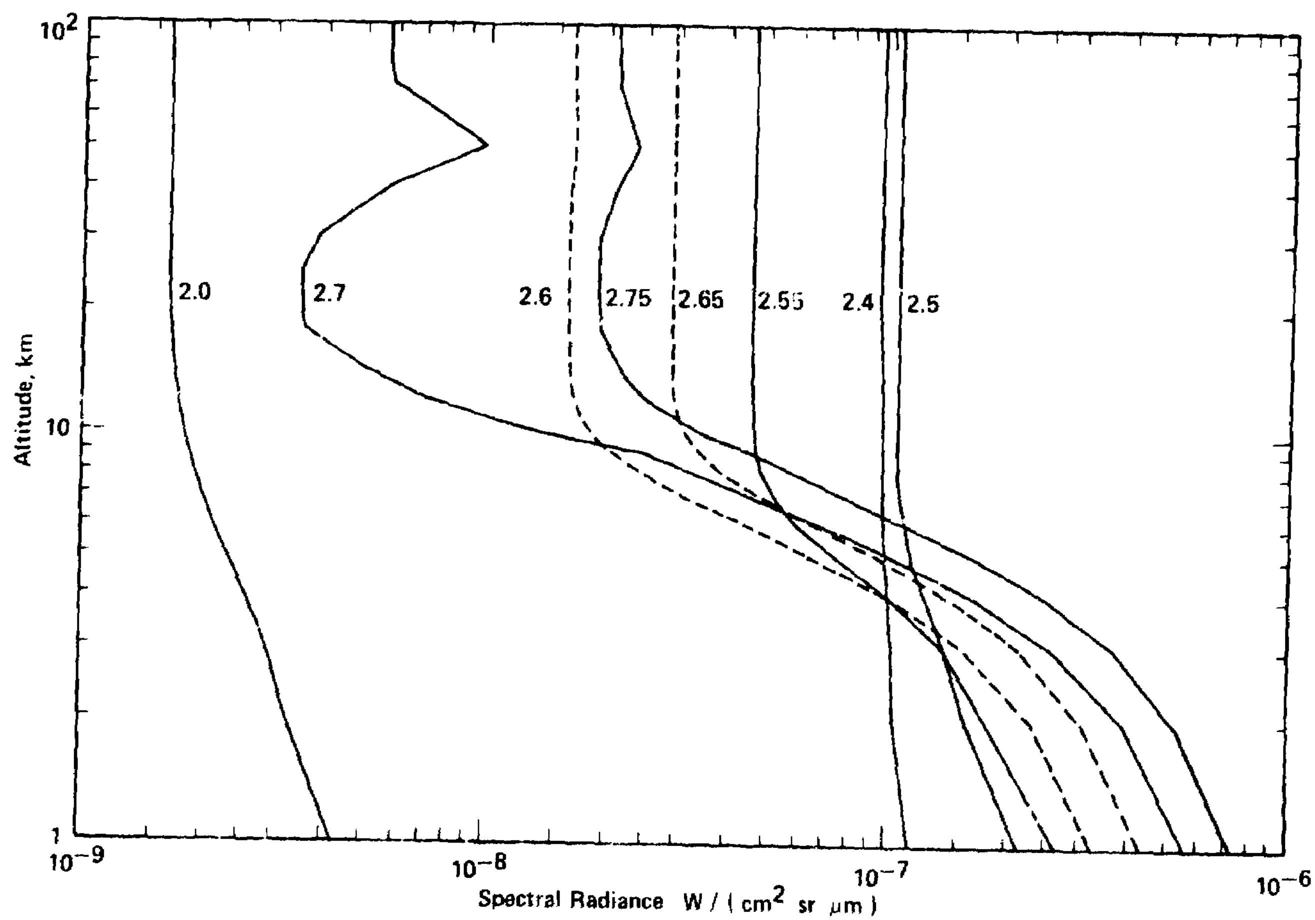


Figure 7–2a. Altitude dependence of spectral radiance (2.0 to 2.5 μm) for nadir–looking sensor.

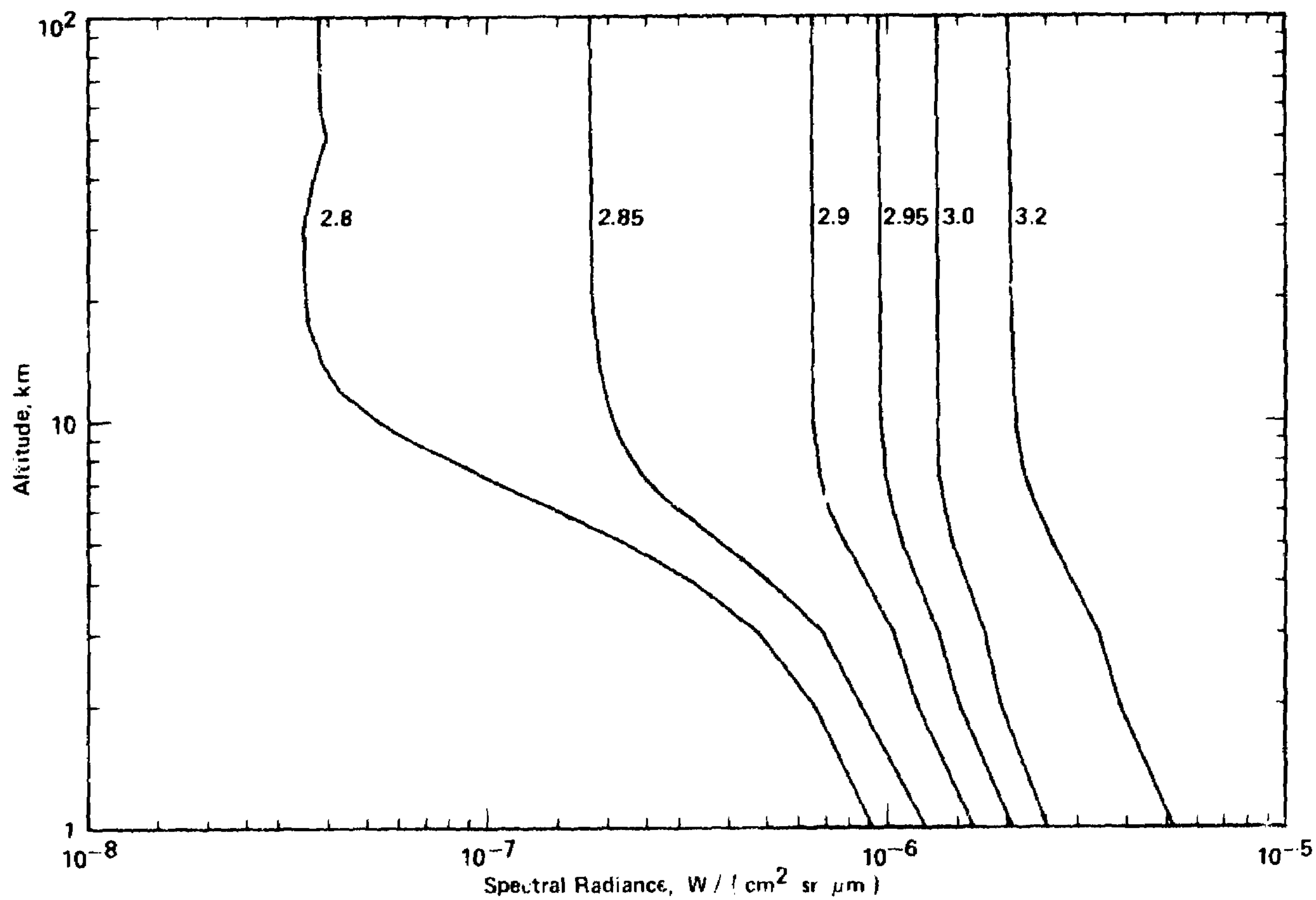


Figure 7-2b. Altitude dependance of spectral radiance (2.8 to 3.2 μm) for nadir–looking sensor.

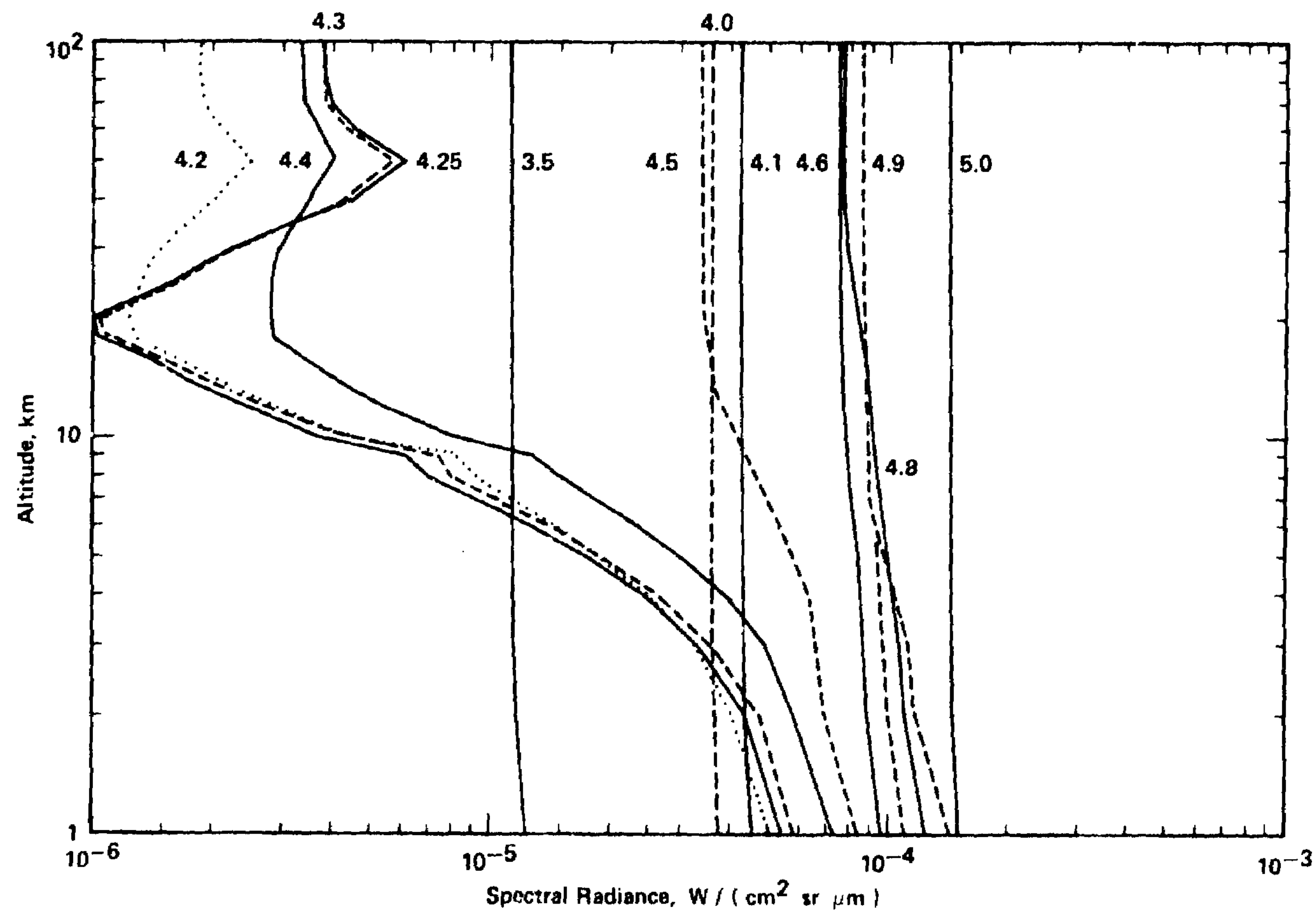


Figure 7–2c. Altitude dependence of spectral radiance (3.5 to 5.0 μm) for nadir-looking sensor.

Table 7-6. Bin altitudes selected for Subroutine SETALT.

Bin No.	Altitudes, km
1	0, 1, 12, 20, 100
2	0, 1, 12, 100
3	0, 1, 3, 12, 100
4	0, 1, 2, 4, 9, 12, 20, 30, 50, 70, 100
5	0, 1, 3, 12, 100
6	0, 1, 12, 100
7	0, 1, 3, 6, 12, 20, 50, 70, 100
8	0, 1, 12, 100
9	0, 1, 12, 30, 100
10	0, 1, 12, 100

Table 7-7. Input and output variables for Subroutine SETALT.

INPUT VARIABLES

Argument List

ALMIN, ALMAX - Minimum and maximum wavelengths for which upwelling natural radiance is to be computed, for (broad) wavelength-band index JBAND. (μm)

JBAND - Index for list of (broad) wavelength bands. (1 to 5)

Data Statements

NBINL1 - Number of wavelength bins (or number of wavelength-bin boundaries minus one).

For L=1,NBINL1+1
BINLAM(L) - Wavelength of bin-boundary L. (μm)

For I=1,NALTL(M), M=1,NBINL1
NALTL(M) - Number of altitudes for wavelength-bin M.

HUPWEL(I,M) - Altitude-I for wavelength-bin M. (km)

(continued)

Table 7-7. Input and output variables for Subroutine SETALT (Cont'd).

OUTPUT VARIABLES

UPWELS Common

For JBAND = J=1,5; I=1,NALT(J)

NALT(J)	-	Number of altitudes for (broad) wavelength-band index JBAND
ZKM(I,J)	-	Altitudes of Point V above reference altitude (UPWALT) at which upwelling natural radiance is computed for (broad) wavelength-band index JBAND. (km)

7-3.3 Other Initialization Routines

7-3.3.1 DSA System

Comments in our listing of Program DRVUPW define the six words and/or arrays that are initialized there before calling QINITL. We also state how to estimate minimum storage requirements for high speed memory in terms of the number and sizes of datasets. For more information on the GRC DSA System, see SP-78. The version of the DSA System we have used was prepared by L. Ewing of G.E. Tempo. Whereas it differs somewhat from the GRC version,it is said to be equivalent, at least for the current application.

7-3.3.2 SAI Routines (ATMOSU, CLOUDU)

Full documentation is given for Subroutines ATMOSU and CLOUDU in Volumes 14a-I and 24, respectively.

7-3.3.3 G.E. Tempo Routines (TRANSB, SHELLS)

The purpose of Subroutine TRANSB is briefly described in Table 7-3a and in Volume 31 (p. 74). Our more detailed summary of its input and output variables is given in Table 7-8.

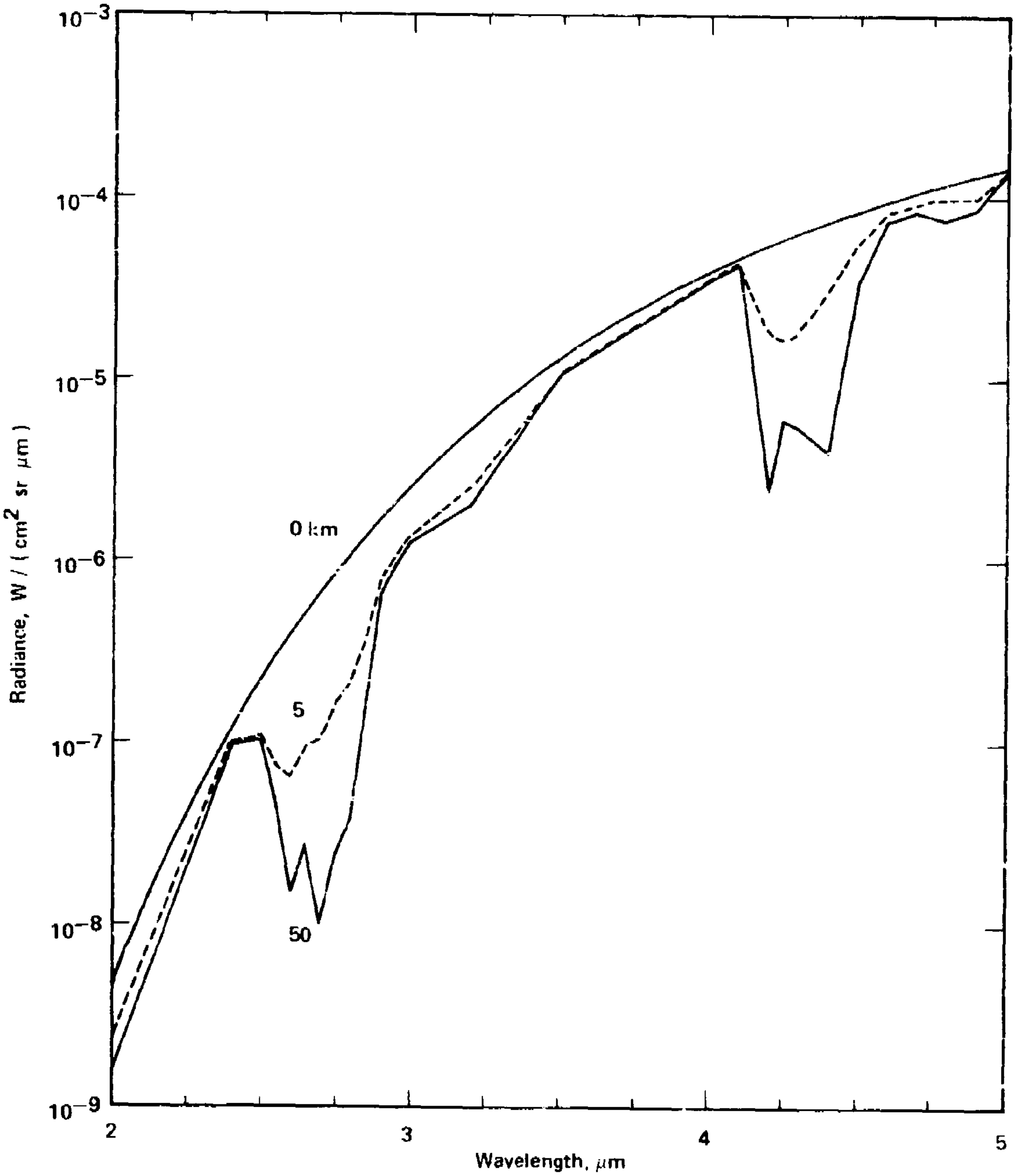


Figure 7–3. Wavelength dependence of spectral radiance (2.0 to 5.0 μm) at 0–, 5–, and 50–km altitude for nadir–looking sensor.

Table 7-8. Input and output variables for Subroutine TRANSB.

INPUT VARIABLES

Argument List

LBAND - List Header Variable (LHV) for Wavelength Bands Dataset-BN (No. 114). Strictly, LBAND is the pointer (i.e., it contains the (Q-array) address) for the list header of the Wavelength Bands Dataset-BN. In GRC usage, LBAND is stored as Word-12 of Dataset-ST (No. 111). In the SAI stand-alone version of the NBR Module, Dataset-ST (No. 111) is not used, but LBAND is still generated in Program DRVUPW and used as the LHV for Dataset-BN.

OPTION Common

TRNSOPT - Logical variable affecting (a) procedure for converting the basic 5-cm^{-1} resolution band-model parameters to those for the user-specified resolution and (b) possible redundancy of output data if user-selected bands overlap with common spectral intervals.

=.TRUE., TRANSB provides:
(a) in-band (more precisely, "in-interval") averaged band-model parameters. (There is no limit on the allowed coarseness of the resolution. If resolution finer than 5-cm^{-1} is requested, the code will compute answers, but they may have little or no physical reality.)
(b) band-model parameters for each interval within a band (even though bands may overlap), and the bands are ordered as in the Wavelength Bands Dataset-BN (No. 114).

=.FALSE., TRANSB provides:
(a) band-model parameters at a (below-defined) resolution that may be finer than the requested spectral intervals. In this case the TRANSB-generated resolution (or subinterval) is 0.5 of the narrowest user-specified wavenumber interval, but within the range of 5 to 50 cm^{-1}. The lower edge of the first output interval lies at the lower edge of the lowest wavenumber spectral interval.
(b) non-redundant information for intervals in overlapping bands. (If bands don't overlap, there is nothing to eliminate, of course.)
Note: For additional information regarding use of these band-model parameters, see comments under FAST in Table 6-10 for Subroutine TRANS.

(continued)

Table 7-8. Input and output variables for Subroutine TRANSB (Cont'd).

XYZCOM Common

ITMTE - Auxiliary input data file number (=2 in Program DRVUPW).

LTMTE - Auxiliary output data file number (=3 in Program DRVUPW).

"Dataset-BN"

Note: The spelling (BN) is an unfortunate artifact from the original development of the routine by L. Ewing of G.E. Tempo. We are really dealing with Words-3, -4, and -6 of the GRC dictionary Dataset-BI (No. 115) and not Dataset-BN (No. 114).

WLO BN, WHI BN - Lowest and highest wavenumbers of spectral interval over which band-model parameters are to be averaged (cm^{-1})

TFLAG BN - Flag to denote whether the wavelength or wavenumber (corresponding to the argument of TFLAG BN) is associated with the first, intermediate, or last spectral division in a band of (ascending) wavelengths or (ascending) wavenumbers.
=1.0, First spectral division (lowest wavelength) in a wavelength band or last spectral division (highest wavenumber) in a wavenumber band.
=0.0, Intermediate spectral division.
=2.0, Last spectral division (highest wavelength) in a wavelength band or first spectral division (lowest wavenumber) in a wavenumber band.

Input Binary File

TAPIN - Equivalenced to ITMTE. Contains band-model parameters for 5-cm^{-1} resolution.

WSL, WSH - Lower and higher wavenumber of 5-cm^{-1} interval for the sets 1997.5(5.0)4997.5 cm^{-1} and 2002.5(5.0)5002.5 cm^{-1}, respectively. (cm^{-1})

For I=1,10; N=1,10
SOD(I,N), DEI(I,N) - Mean absorption coefficient and inverse of mean line-spacing parameter (or the effective line density) for species-N at temperature-index-I for the wavenumber interval (WSL, WSH). (1/cm at STP, lines/cm^{-1})

(continued)

Table 7-8. Input and output variables for Subroutine TRANSB (Cont'd).

OUTPUT VARIABLES

Output Binary File

TAPOT - Equivalenced to LTMTE. Contains band-model parameters, derived from the 5-cm^{-1} resolution data, for the user-specified interval DW either (a) communicated through the Dataset-BI if TRNSOPT=.TRUE. or (b) set by an algorithm if TRNSOPT=.FALSE.. The algorithm is that DW equals 0.5 of the minimum DW communicated through the Dataset-BI, but not less than 5.0 or more than 50 cm^{-1}.

WL, WH - Lower and higher wavenumbers of interval DW. (cm^{-1})

S(I,N), DE(I,N) - Mean absorption coefficient and inverse of mean line-spacing parameter (or the effective line density) for species-N at temperature-index-I for the wavenumber interval DW. (1/cm at STP, lines/cm^{-1})

Note: In Volume 31, L. Ewing briefly comments (on p. 74) on the algorithm in Subroutine TRANSB for using the band-model parameters for the 5-cm^{-1} resolution (WSL, WSH) to obtain the band-model parameters for the output spectral interval (WL, WH), regardless of TRNSOPT being TRUE or FALSE. The description is not fully satisfying since the evidence is not given. In any event, we record here the formulas used in TRANSB:

DE(lines/cm^{-1}) $\equiv$ DE(I,N) as output from Subroutine TRANSB
$\equiv$ DEI(I,N) as input to Subroutine TRANS
= inverse of mean line-spacing parameter for species-N at temperature-index-I, or the effective line density for the interval

DW $\equiv$ (WL, WH) in TRANSB
$\equiv$ (WTL, WTH) in TRANS.

$$\boxed{DE = [\sum_j F_j/\Delta_j]^{-1}}$$

S(cm^{-1} at STP) = S(I,N) as output from Subroutine TRANSB
$\equiv$ SOD(I,N) as input to Subroutine TRANS
= mean absorption coefficient for species-N at temperature-index-I for the interval

(continued)

Table 7-8. Input and output variables for Subroutine TRANSB (Cont'd).

DW ≡ (WL, WH) in TRANSB
≡ (WTL, WTH) in TRANS.

$$\boxed{S = \frac{\sum_j k_j F_j/\Delta_j}{\sum_j F_j/\Delta_j}}$$

where:

k_j ≡ SOU(I,N) [<u>not</u> same as input to TRANS]

= mean absorption coefficient for species-N at temperature-index-I for the 5-cm^{-1} interval (WSL, WSH). (cm^{-1} at STP)

Δ_j ≡ DEI(I,N) [<u>not</u> same as input to TRANS]

= inverse of mean line-spacing parameter, or the effective line density for the 5-cm^{-1} interval (WSL, WSH). (lines/cm^{-1})

F_j ≡ FRAC(WL, WH, WSL, WSH)

= fraction of the user interval DW ≡ (WL, WH) covered by the (5-cm^{-1}) basic tape interval (WSL, WSH).

$$\sum_{j=1}^{J} F_j = 1$$

It is easily shown that, in the special case of uniform line spacing over J intervals, Ewing's formulas give the expected results:

$$DE \rightarrow \frac{1}{\frac{F_o}{\Delta_o}\sum_{j=1}^{J} 1} = \frac{\Delta_o}{F_o J} = \Delta_o$$

$$S \rightarrow \frac{\frac{F_o}{\Delta_o}\sum_{j=1}^{J} k_j}{\frac{F_o}{\Delta_o}\sum_{j=1}^{J} 1} = \frac{\sum_{j=1}^{J} k_j}{J} .$$

The purpose of Subroutine SHELLS is briefly described in Table 7-3a and very briefly in Volume 31 (p. 68). Our summary of its input and output variables is given in Table 7-9. In our version of Subroutine SHELLS we have added statements (a) to print a table of all the atmospheric properties computed at the shell boundaries and (b) to compute and print the water content of the atmosphere along a vertical path above each of the shell boundaries. The water content is expressed in units of precipitable centimeters. This computation was added to facilitate comparisons with other workers.

Table 7-9. Input and output variables for Subroutine SHELLS.

INPUT VARIABLES

ATMOUP Common

PP - Pressure. (dyne/cm^2)

TT - Temperature. (deg K)

SNI(I) - Density of species-I. (cm^{-3})

Particular species are indicated as follows:

N	I=IMAP(N)	SNI(I)	Set by Subroutine
1	8	NO^+	SPCMIN
2	11	NO	IONOSU
3	21	N_2O	SPCMIN
4	15	NO_2	SPCMIN
5	14	O_3	SPCMIN
6	6	CO_2	ATMOSU
7	20	CO	SPCMIN
8	22	CH_4	SPCMIN
9	16	H_2O	SPCMIN
10	18	OH	SPCMIN

XYZCOM Common

FACT - Parameter controlling the number of altitude boundaries and their spacing. Nominal value is 1.0, but a reasonable range is between 0.1 and 10.0 (per L. Ewing). The original algorithm provided by G.E. Tempo allowed a maximum of 81

(continued)

Table 7-9. Input and output variables for Subroutine SHELLS (Cont'd).

boundaries, but a revision by GRC reduced this number to 61 and also altered the spacings. We have adopted the GRC revision. In the comments of our listing of SHELLS, we have given the boundary altitudes per GET algorithm for FACT=1.0 and per GRC algorithm for FACT=0.1, 1.0, and 10.0. Here, we record the results for GRC's FACT=1.0 (X_0=1.25, X_1=3.125, X_2=7.8125).

J	HS	J	HS	J	HS
1	0.	10[a]	13.125	18[b]	42.8125
2	1.25	11	16.250	19	50.6250
3	2.50	12	19.375	20	58.4375
4	3.75	13	22.500	21	66.2500
5	5.00	14	25.625	22	74.0625
6	6.25	15	28.750	23	81.8750
7	7.50	16	31.875	24	89.6875
8	8.75	17	35.000	25	97.5000
9	10.00				

[a] JCHNG1 [b] JCHNG2

OUTPUT VARIABLES

XYZCOM Common

NS - Number of altitude boundaries

For J=1,NS; N=1,10
HSHELL(J), TS(J), PS(J), XNSPEC(J,N) - Altitude, temperature, pressure, and species-N density at altitude-boundary J (cm, deg K, atm, cm^{-3})

7-4 INTEGRATION OF NBR MODULE INTO ROSCOE-IR

7-4.1 General

Table 7-10 provides a guide to the integration of the NBR-Module routines into ROSCOE-IR. For these routines, we now mention some of the differences between the routine in the stand-alone version of the NBR Module and the routine in ROSCOE-IR.

Table 7-10. Guide to integration of NBR Module into ROSCOE-IR.

NBR-Module routine[a]		Program in ROSCOE-IR calling NBR-Module routine	
Name	Purpose of call		
QINITL	b	ROSMAIN,[c]	Overlay (0,0)
ATMOSU[d]	e	ATKGEN,	Overlay (3,1)
CLOUDO	f	ATKGEN,	Overlay (3,1)
TRANSB	g	ATKGEN,	Overlay (3,1)
SHELLS	h	ATKGEN,	Overlay (3,1)
SETALT	i	OLOOK,	Overlay (3,25)
UPWELL	j	OLOOK,	Overlay (3,25)
UPWELT	k	EMISCAT,	Overlay (3,31)

[a] Each of these routines (except UPWELT which is not in the stand-alone version of the NBR Module) is called by the driver, Program DRVUPW.

[b] To initialize the DSA routines.

[c] Strictly, Subroutine QINITL is called by Subroutine ROSCOE which is called by Program ROSMAIN.

[d] Known as ATMOS in ROSCOE-IR.

[e] To initialize atmospheric routines depending on location and time.

[f] To initialize statistical-cloud submodel properties.

[g] To prepare, from the basic 5-cm^{-1} resolution band-model parameters file, band-model parameters for prescribed spectral resolution.

[h] To establish atmospheric grid for h $\leq$100 km.

[i] To determine the altitudes (depending on wavelength of interest) at which Subroutine UPWELL is to compute the upwelling natural background radiation.

[j] To compute, for a Point V at each of a set of NALT altitudes above a given geographic position, characterized by Material MSM and Property DD(MSM), the natural upwelling spectral radiance directed toward Point V from Points P on Earth's surface with respect to Point V at NNADIR representative nadir angles and NAZI representative azimuth angles.

[k] To interpolate the upwelling radiation array UPRADN(I,M,L) in altitude (I) and select the appropriate band-interval (M) in broad-band (L). For altitudes ZKM $\geq$ 12 km, UPRADN is not the cloud-free result but the 50-percentile of the radiance distribution function for statistical clouds (if included in the problem).

Our QINITL was prepared by G.E. Tempo and, while different from GRC's, is said to be equivalent for the present purposes.

Our ATMOSU, documented in Volume 14a-1, does not contain the DSA System as does the GRC version.

GRC's CLOUDO, more restricted than SAI's documented in Volume 24, initializes only statistical (as opposed to deterministic) cloud data. However, with respect to the NBR Module which contains only statistical clouds, the two versions are presumably equivalent (except for GRC's DSA), although the details have not been verified.

Subroutine TRANSB contains the DSA System in both versions and should be the same in both versions except for one small difference. The logical variable TRNSOPT enters through Common OPTION in the SAI version whereas in the GRC version TRNSOPT is set to Word-27 (FAST or GOOD) in the Basic Dataset-BO (No. 9).

Our Subroutine SHELLS is the same as the GRC version in all essential aspects. (See Section 7-3.3.3 for small differences.)

Subroutine SETALT should be the same in both versions.

Subroutine UPWELL, written in terms of the DSA System in both versions, should be essentially the same. SAI's version contains many print statements properly deleted in the GRC version. The comment regarding TRNSOPT in Subroutine TRANSB applies here, too.

Subroutine UPWELT, not in the stand-alone version of the NBR Module, is discussed in Section 7-4.2.

7-4.2 Subroutine UPWELT

Subroutine UPWELT was prepared by GRC to select the appropriate wavenumber interval and to interpolate in altitude the upwelling natural radiation

array, UPRADN(I,K,JBAND). For altitudes ZKM $\geq$ 12 km, UPRADN is not the cloud-free result but the 50-percentile of the radiance distribution function for statistical clouds (if included in the problem). Table 7-11 gives the input and output variables for Subroutine UPWELT.

Table 7-11. Input and output variables for Subroutine UPWELT.

INPUT VARIABLES		
Argument List		
HCM	-	Altitude at which upwelling spectral radiance is desired in Program EMISCAT. (cm)
WL, WH	-	Lower and higher limits of wavenumber interval for which upwelling spectral radiance is desired (set in Program EMISCAT from Dataset-BI). (cm^{-1})
UPWELS Common		
For I=1,NALTJ; L=1,NWAVEJ; M=1,NBANDS		
NALT(M)	-	Number of altitudes ZKM(I,M) at which upwelling spectral radiance has been computed for (broad) wavelength-band index M. Defines NALTJ.
ZKM(I,M)	-	Altitudes of Point V above UPWALT at which upwelling radiance is computed. (km)
NWAVE(M)	-	Number of wavenumbers at which the upwelling spectral radiance has been computed for (broad) wavelength-band index M. Defines NWAVEJ.
UPRADN(I,L,M)	-	The nadir-averaged value of UPRADA(I,J,L). See Table 6-2 for Subroutine UPWELL. In the GRC version, for altitudes ZKM $\geq$ 12 km and if clouds are included, UPRADN is not the cloud-free result but the 50-percentile of the radiance distribution function for statistical clouds. [W/(cm^2 sr cm^{-1})]
WV(L,M)	-	The array of central wavenumbers corresponding to (broad) wavelength-band index M. Set in Program OLOOK from Dataset-BI. (cm^{-1})
NBANDS	-	Number of (broad) wavelength bands.
OUTPUT VARIABLES		
Argument list		
RADUP	-	The value of the upwelling natural radiation for the wavenumber interval (WL,WH), averaged over the downward hemisphere and logarithmically interpolated from the array UPRADN for the input altitude HCM. [Photons/(cm^2 sec sr cm^{-1})]

SECTION 8

LISTING OF SELECTED ROUTINES

In this section we provide a FORTRAN listing of those routines in the NBR Module which have not been published elsewhere (or at least not in the form in which they are used in the NBR Module). An index to such routines, as well as their originator, is given in Table 8-1. Table 7-3a tells where listing of the other routines have been published.

Table 8-1. Index to routines with FORTRAN listing in Volume 27.

Routine	Originator[a]	Page	Routine	Originator[a]	Page
DRVUPW	SAI	227	RINOUT	SAI	268
ACCUM	GET	237	SEGMENT	GET	271
AEROSOL	VI	238	SETALT	SAI	275
AGAGEO	SAI	243	SHELLS	GET	277
ATMRAD	GET	244	SOLRAD	SAI	280
CANGLE	SAI	249	SORTLJ	SAI	281
DOT	GET	249	STEP	GET	282
ERF	SAI	249	STEPS	GET	284
ESURF	SAI	250	SUBVEC	GET	284
FRAC	GET	254	SURRAD	SAI	285
FRESNL	SAI	255	TANGEO	SAI	295
GCRCLE	SAI	257	TRANS	GET	296
GEOREA	SAI	258	TRANSB	GET	303
GEOTAN	SAI	258	TRNSCO	GET	308
GEOXYZ	SAI	259	UNITV	GET	312
GLITTR	SAI	260	UPWELL	SAI	312
PATH	GET	265	VLIN	GET	333
PLANCK	GET	267	XMIT	GET	333
REATAN	SAI	267			

[a]SAI comments inserted in routines developed elsewhere are denoted by CLJ in the first three columns.

```
      PROGRAM DRVUPW (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2,TAPE3,
     1 TAPE8)
CC
CC    THIS ROUTINE IS PROVIDED TO DRIVE AND TEST SUBROUTINE UPWELL AND
CC    THE RELATED ROUTINES WHICH COMPRISE THE NATURAL BACKGROUND
CC    RADIATION MODEL FOR THE UNDISTURBED ATMOSPHERE, INCLUDING A
CC    STATISTICAL TREATMENT OF NATURAL CLOUDS.
CC
CC    *** HISTORICAL STATEMENT ***
CC        BECAUSE WE WERE GIVEN (6/1/78) A MOLECULAR TRANSMITTANCE
CC        MODULE BY G.E. TEMPO THAT HAD SEVERAL ROUTINES (DRIVER PROGRAM
CC        ATMOST AND SUBROUTINES ATMRAD, TRANSB, AND TRNSCO) WRITTEN IN
CC        TERMS OF THE GRC DSA SYSTEM, WE PREPARED TWO VERSIONS OF THE
CC        NATURAL BACKGROUND RADIATION (NBR) MODULE.  ONE VERSION, WHICH
CC        WE REGARDED AS THE BASIC VERSION, USED DSA IN THE SAI DRIVER
CC        PROGRAM DRVUPW, SUBROUTINE UPWELL, AND THE ABOVE-NAMED GET
CC        SUBROUTINES.  THE OTHER VERSION DID NOT USE DSA.  BOTH
CC        VERSIONS WERE TESTED ON SEVERAL PROBLEMS AND GAVE THE SAME
CC        ANSWERS.
CC        (HISTORICALLY, WE FIRST PREPARED THE DSA VERSION AND THEN
CC        DEVELOPED THE NON-DSA VERSION BY USING A SET OF ABOUT 235
CC        CORRECTION CARDS (90 ACTION CARDS AND ABOUT 145 COMMENT
CC        CARDS).  THEN, THE NON-DSA VERSION WAS AVAILABLE FROM A
CC        PROGRAM LIBRARY (IN THE CONTEXT OF THE CDC UPDATE UTILITY
CC        PROGRAM) AND THE DSA VERSION WAS OBTAINED BY USING THE *YANK
CC        UPDATE DIRECTIVE TO DELETE THE NON-DSA CORRECTION SET.)
CC        WE EFFECTED THE REMOVAL OF THE DSA-USAGE BY A NON-STANDARD
CC        METHOD WHICH RETAINED AS MUCH OF THE DSA CODING AS POSSIBLE
CC        BUT WITH NEW MEANINGS TO MANY OF THE DSA VARIABLES.  THE DSA
CC        STATEMENTS THAT COULD NOT BE USED WERE COMMENTED (C-DSA) AND
CC        FOLLOWED WITH THE NECESSARY REPLACEMENT STATEMENTS.
CC        (THIS PROCEDURE WAS FEASIBLE FOR US BECAUSE ONLY TWO DATASETS
CC        WERE INVOLVED.  IT MAY NOT BE FEASIBLE FOR A CASE WITH MANY
CC        DATASETS.)
CC
CC        IN JANUARY 1980, DURING A REVIEW OF THE INCORPORATION OF THE
CC        NBR MODULE INTO ROSCOE, NUMEROUS ERRORS WERE DISCOVERED, SOME
CC        OF WHICH WERE COMPOUNDED OWING TO THE FACT THAT THE DATASETS
CC        USED IN THE GET ROUTINES WERE INCONSISTENT WITH THE GRC
CC        DICTIONARY DATASETS.  THE NON-STANDARD DATASETS HAVE NOW BEEN
CC        REPLACED BY THE STANDARD DATASETS (EXCEPT IN SUBROUTINE
CC        TRANSB).  AN EXTENSIVE REVISION OF THE (STAND-ALONE) NBR
CC        MODULE WAS REQUIRED TO BRING IT INTO A CLOSE CORRESPONDENCE
CC        WITH THE CORRECTED VERSION IN THE ROSCOE CODE.  CONSEQUENTLY,
CC        IN THIS FINAL VERSION OF THE NBR MODULE, WE DO EMPLOY THE GRC
CC        DSA SYSTEM (BUT IN A GET VERSION AND NOT IN THE GRC VERSION)
CC        WHERE APPROPRIATE.  WE DO NOT PROVIDE A NON-DSA VERSION.
CC
      COMMON QNAREA, QWAREA(10), QFREHD, QNDTST, QNLNKS, QZSIZE,
     1       QNZBLK, QZHEAD, QCOUNT(30), QDSIZE(10), QNSIZE, QLUNIT(10),
     2       QERLUN, QFBITS(2,10), Q(1)
      INTEGER QNAREA, QWAREA, QFREHD, QNDTST, QNLNKS, QZSIZE, QNZBLK,
     1        QZHEAD, QCOUNT, QDSIZE, QMODLK, QNSIZE, QLUNIT, QFIELD,
     2        QERLUN, QFBITS, QCRSIZ
      COMMON / TIME / IYRS, IMONS, IDAYS, ZT, PLAT, PLON, UT, GAT, FYR,
     1                FST, RHO5KM, CHI
      COMMON / VPC / WVFLAG, METHOD
```

```
      COMMON / ZHTEMP / XX(63), TPFLAG                                  DRVUPW
      COMMON / XYZCOM / ITMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81),   DRVUPW
     1                  XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS,  DRVUPW
     2                  FACT                                            DRVUPW
      COMMON / OPTION / TRNSOPT                                         DRVUPW
      COMMON / OPTIN1 / RADSW                                           DRVUPW
      COMMON / XY / TT(10)                                              DRVUPW
      COMMON/AEROK /  KVIS, KPTYPE                                      DRVUPW
      COMMON/PARAMS/  INFIL,IOFIL,PI,ERAD,DGTOR,RTODG                   DRVUPW
      COMMON/UPWELS/  UPWALT,UPWLON,UPWLAT,NALT(5),ZKM(13,5),NNADIR,    DRVUPW
     *                NAZI,NWAVE(5),IDAYV,CLDFLG,UPRADN(13,10,5),       DRVUPW
     *                WV(10,5),IKM,NBANDS                               DRVUPW
      COMMON/UPWELS1/                                                   DRVUPW
     2                R010(6,10),R010A(6,10,10),R010N(6,10),            DRVUPW
     3                R025(6,10),R025A(6,10,10),R025N(6,10),            DRVUPW
     4                R050(6,10),R050A(6,10,10),R050N(6,10),            DRVUPW
     5                R090(6,10),R090A(6,10,10),R090N(6,10),            DRVUPW
     6                R100(6,10),R100A(6,10,10),R100N(6,10)             DRVUPW
     7                          ,ARCVA(6,10,10),ARCVN(6,10)             DRVUPW
      COMMON/UPWELS3/ UPRAD(6,10),UPRADA(13,10,10)                      DRVUPW
CCC        II=NALTJ,  JJ=NNADIR,  KK=NAZI,  LL=NWAVEJ,  NN=NBANDS       DRVUPW
CCC        UPRAD(KK,LL), UPRADA(II,JJ,LL), UPRADN(II,LL,NN)             DRVUPW
      DIMENSION QXXX(2000)                                              DRVUPW
      EQUIVALENCE ( Q, QXXX )                                           DRVUPW
      DIMENSION DD(7),WW(10),DW(10),ALAM(10),DLAM(10)                   DRVUPW
      DIMENSION BNLO  BN(1), BNHI  BN(1), WLO  BN(1), WHI  BN(1),       DRVUPW
     *          LINRV BN(1)                                             DRVUPW
      EQUIVALENCE ( Q(1), BNLO  BN ), ( Q(2), BNHI  BN ),               DRVUPW
     *            ( Q(3), WLO   BN ), ( Q(4), WHI   BN ),               DRVUPW
     *            ( Q(5), LINRV BN )                                    DRVUPW
      DIMENSION BNLO  BI(1), BNHI  BI(1), WLO   BI(1), WHI   BI(1),     DRVUPW
     *          BKGND BI(1), TFLAG BI(1), TRANS BI(1), IDSBX BI(1)      DRVUPW
      EQUIVALENCE ( Q(1), BNLO  BI ), ( Q(2), BNHI  BI ),               DRVUPW
     *            ( Q(3), WLO   BI ), ( Q(4), WHI   BI ),               DRVUPW
     *            ( Q(5), BKGND BI ), ( Q(6), TFLAG BI ),               DRVUPW
     *            ( Q(7), TRANS BI ), ( Q(8), IDSBX BI )                DRVUPW
      LOGICAL  SPCULR                                                   DRVUPW
      LOGICAL RADSW, TRNSOPT                                            DRVUPW
      DATA TT / 200., 300., 500., 750., 1000., 1500., 2000., 3000.,     DRVUPW
     *          5000., 7000. /                                          DRVUPW
      DATA PI / 3.14159265 /                                            DRVUPW
      DATA DD / 0.10, 10., 0.50, 0., 0., 0., 0.5 /                      DRVUPW
CCC                                                                     DRVUPW
CC         FILE NAMES                                                   DRVUPW
CC          * TAPE2 AND TAPE3 ARE IDENTIFIED IN PROGRAM DRVUPW WITH ITMTE DRVUPW
CC            AND LTMTE, RESPECTIVELY.                                  DRVUPW
CC            ITMTE (ALIAS TAPIN) AND LTMTE (ALIAS TAPOT) ARE READ AND  DRVUPW
CC            WRITTEN, RESPECTIVELY, BY SUBROUTINE TRANSB.              DRVUPW
CC          * TAPE8 IS WRITTEN BY SUBROUTINE UPWELL AND READ BY PROGRAM DRVUPW
CC            DRVUPW.                                                   DRVUPW
CC         READ OR OTHERWISE SET THE FOLLOWING PARAMETERS...            DRVUPW
CC                                                                      DRVUPW
CC            PARAMETER  IN COMMON  DEFINED IN   READ/SET  COMMENT      DRVUPW
CC            ---------  ---------  -----------  --------  -------      DRVUPW
CC            KVIS       AEROK      SUB. AEROSOL    R                   DRVUPW
CC            KPTYPE     AEROK      SUB. AEROSOL    R                   DRVUPW
CC                                                                      DRVUPW
```

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CC        RADSW      OPTINI     SUB. UPWELL   R                     DRVUPW   116
CC                                                                  DRVUPW   117
CC        TRNSOPT    OPTION     SUB. TRANS    R          I          DRVUPW   118
CC                                                                  DRVUPW   119
CC        INFIL      PARAMS                       S      B1         DRVUPW   120
CC        IOFIL      PARAMS                       S      B2         DRVUPW   121
CC        PI         PARAMS                       S                 DRVUPW   122
CC        ERAD       PARAMS                       S      C          DRVUPW   123
CC        DGTOR      PARAMS                       S      D1         DRVUPW   124
CC        RTODG      PARAMS                       S      D2         DRVUPW   125
CC                                                                  DRVUPW   126
CC        IYRS       TIME       DRVATM        R          E          DRVUPW   127
CC        IMONS      TIME       DRVATM        R          E          DRVUPW   128
CC        IDAYS      TIME       DRVATM        R          E          DRVUPW   129
CC        ZT         TIME       DRVATM        R          E          DRVUPW   130
CC        PLAT       TIME       SUB. SOLZEN       S                 DRVUPW   131
CC        PLON       TIME       SUB. SOLZEN       S                 DRVUPW   132
CC        GCO        --         DRVATM        R          E,F1       DRVUPW   133
CC        GLO        --         DRVATM        R          E,F2       DRVUPW   134
CC                                                                  DRVUPW   135
CC        UPWALT     UPWELS     SUB. UPWELL       S                 DRVUPW   136
CC        UPWLON     UPWELS     SUB. UPWELL       S                 DRVUPW   137
CC        UPWLAT     UPWELS     SUB. UPWELL       S                 DRVUPW   138
CC        NNADIR     UPWELS     SUB. UPWELL   R                     DRVUPW   139
CC        NAZI       UPWELS     SUB. UPWELL   R                     DRVUPW   140
CC        NWAVE(5)   UPWELS     SUB. UPWELL       S                 DRVUPW   141
CC        CLDFLG     UPWELS     SUB. UPWELL   R                     DRVUPW   142
CC        MSM        --         SUB. UPWELL   R                     DRVUPW   143
CC        DD(MSM)    --         SUB. UPWELL       S      G          DRVUPW   144
CC        SPCULR     --         SUB. UPWELL   R                     DRVUPW   145
CC                                                                  DRVUPW   146
CC        WVFLAG     VPC        DRVATM            S      E          DRVUPW   147
CC        METHOD     VPC        DRVATM            S      E          DRVUPW   148
CC                                                                  DRVUPW   149
CC        TT(I)      XY         SUB. TRANS        S      G          DRVUPW   150
CC                                                                  DRVUPW   151
CC        ITMTE      XYZCOM     SUB. TRANSB       S                 DRVUPW   152
CC        LTMTE      XYZCOM     SUB. TRANSB       S                 DRVUPW   153
CC        NMOLS      XYZCOM     SUB. TRANS        S                 DRVUPW   154
CC        FACT       XYZCOM     SUB. SHELLS   R                     DRVUPW   155
CC                                                                  DRVUPW   156
CC        TPFLAG     ZHTEMP     DRVATM            S      E          DRVUPW   157
CC        ----------------------------------------------------      DRVUPW   158
CC        B1  INPUT FILE FOR STATISTICAL CLOUD MODEL                DRVUPW   159
CC        B2  OUTPUT FILE FOR STATISTICAL CLOUD MODEL               DRVUPW   160
CC        C   EARTH RADIUS, KM                                      DRVUPW   161
CC        D1  DEGREES-TO-RADIANS                                    DRVUPW   162
CC        D2  RADIANS-TO-DEGREES                                    DRVUPW   163
CC        E   PROGRAM DRVATM FOR SUBROUTINES ATMOSU, SPCMIN, ETC.   DRVUPW   164
CC        F1  USED TO SET PLAT                                      DRVUPW   165
CC        F2  USED TO SET PLON                                      DRVUPW   166
CC        G   SET BY DATA STATEMENT                                 DRVUPW   167
CC        H1  IDEALLY BUT NOT NECESSARILY SET TO PLAT               DRVUPW   168
CC        H2  IDEALLY BUT NOT NECESSARILY SET TO PLON               DRVUPW   169
CC        I   ALSO SEE SUBROUTINE TRANSB                            DRVUPW   170
CCC                                                                 DRVUPW   171
CC      IN THE FOLLOWING SEVEN STATEMENTS, THE DSA MEANINGS ARE ... DRVUPW   172
```

```
CC        QNAREA    = NUMBER OF STORAGE AREAS.                             DRVUPW
CC        QWAREA(1) = NUMBER OF WORDS OF HIGH-SPEED MEMORY (SCM).          DRVUPW
CC                    NOTE THAT THROUGH THE INITIALIZATION PERFORMED BY  DRVUPW
CC                    SUBROUTINE QINITL, THE MAXIMUM NUMBER OF WORDS     DRVUPW
CC                    AVAILABLE IN THE Q-ARRAY IS SET EQUAL TO           DRVUPW
CC                    QWAREA(1).  THUS THE LENGTH OF BLANK COMMON        DRVUPW
CC                    EQUALS THE SUM OF QWAREA(1) AND THE NUMBER (89)    DRVUPW
CC                    OF WORDS REQUIRED FOR THE BLANK-COMMON VARIABLES   DRVUPW
CC                    OTHER THAN Q.                                      DRVUPW
CC                    THE MINIMUM VALUE REQUIRED FOR QWAREA(1) MAY BE    DRVUPW
CC                    DETERMINED BY NOTING THAT                          DRVUPW
CC                    (A)  THE FIRST TWO WORDS AND THE LAST WORD IN THE  DRVUPW
CC                         Q-ARRAY ARE USED BY THE DSA SYSTEM.           DRVUPW
CC                    (B)  EACH DATASET HAS A ZEROTH WORD.               DRVUPW
CC                    (C)  THE NUMBER OF WORDS USED BY THE Z-BLOCK       DRVUPW
CC                         DATASET IS HARDWIRED TO BE 101 (SUBROUTINE    DRVUPW
CC                         QINITL SETS QZSIZE=100, AND A ZEROTH WORD IS  DRVUPW
CC                         REQUIRED).  ONE MAY DETERMINE THE MINIMUM     DRVUPW
CC                         SIZE REQUIRED FOR THE Z-BLOCK BY NOTING THAT  DRVUPW
CC                         TWO WORDS (A DATASET POINTER WORD AND A LINK  DRVUPW
CC                         WORD) ARE REQUIRED FOR EACH DATASET AND ALSO  DRVUPW
CC                         ONE LIST HEADER WORD FOR THE DATASETS ON A    DRVUPW
CC                         LIST.                                         DRVUPW
CC                    IF TWO BANDS, EACH WITH TWO BAND INTERVALS, ARE    DRVUPW
CC                    USED FOR A SAMPLE PROBLEM, THEN ONE NEEDS          DRVUPW
CC                      FOR TWO DATASETS-BN,          2*(5+1)=12         DRVUPW
CC                      FOR FOUR DATASETS-BI,         4*(8+1)=36         DRVUPW
CC                      FIRST TWO AND LAST WORDS OF Q,       = 3         DRVUPW
CC                      Z-BLOCK,                             =16         DRVUPW
CC                               ZEROTH WORD,          1                 DRVUPW
CC                               DATASETS-BN,    1+2*2 =  5              DRVUPW
CC                               DATASETS-BI, 2*(1+2*2)= 10              DRVUPW
CC                                                    ---                DRVUPW
CC                               Z-BLOCK TOTAL        = 16               DRVUPW
CC                                                          -----        DRVUPW
CC                      TOTAL WORDS                          =67         DRVUPW
CC                    USE OF NEAR-MINIMUM SIZES FOR THE Z-BLOCK AND FOR  DRVUPW
CC                    QWAREA(1) IS HIGHLY RECOMMENDED WHEN ONE WANTS TO  DRVUPW
CC                    USE PDUMP TO SEE WHAT IS GOING ON IN BLANK         DRVUPW
CC                    COMMON.                                            DRVUPW
CC        QWAREA(2) = NUMBER OF WORDS OF  LOW-SPEED MEMORY (LCM).          DRVUPW
CC        QDSIZE(1) = NUMBER OF WORDS IN SMALLEST DATASET.                 DRVUPW
CC        QDSIZE(2) = AN ASSIGNED VALUE OF ZERO IMPLIES THAT DATASETS      DRVUPW
CC                    LARGER THAN THE LAST ASSIGNED INCREMENT WILL BE    DRVUPW
CC                    ALLOCATED THE EXACT NUMBER OF WORDS REQUIRED.      DRVUPW
CC        QERLUN    = LOGICAL UNIT NUMBER OF DEVICE USED FOR SYSTEM        DRVUPW
CC                    ERROR MESSAGES.                                    DRVUPW
CC        QINITL    = THIS SUBROUTINE INITIALIZES OTHER SYSTEM             DRVUPW
CC                    VARIABLES AND SETS UP THE FREE LIST.               DRVUPW
CC                                                                       DRVUPW
      QNAREA = 2                                                         DRVUPW
      QWAREA(1) = 2000                                                   DRVUPW
      QWAREA(2) = 50000                                                  DRVUPW
      QDSIZE(1) = 5                                                      DRVUPW
      QDSIZE(2) = 0                                                      DRVUPW
      QERLUN = 6                                                         DRVUPW
      CALL QINITL                                                        DRVUPW
```

```
CCC
CC * * *  INITIALIZE AMBIENT ATMOSPHERE AFTER SETTING PARAMETERS IN
CC           TIME, VPC, AND ZHTEMP COMMONS.
      READ (5,315) IYRS, IMONS, IDAYS, ZT, GCO, GLO
      WRITE(6,316) IYRS, IMONS, IDAYS, ZT, GCO, GLO
      GCO = GCO * PI / 180.
      GLO = GLO * PI / 180.
      PLAT = .5 * PI - GCO
      PLON = GLO
      WVFLAG = 0.   $   METHOD = 0   $   TPFLAG = 0.
      CALL ATMOSU ( 1, 120. )
CCC
CC * * *  INITIALIZE NATURAL CLOUDS.
CCC
CC          THE STATISTICAL CLOUD SUBMODEL OF THE SAI/PA NATURAL CLOUD
CC          MODEL (NCM) HAS NOW BEEN INTEGRATED INTO THE UPWELLING
CC          NATURAL RADIATION MODEL. (THERE IS NO INTENTION OF INCORPORA-
CC          TING THE DETERMINISTIC CLOUD SUBMODEL.) THE INTERFACE OF THE
CC          UPWELLING NATURAL RADIATION MODEL WITH THE NCM IS ACHIEVED IN
CC          TWO GENERAL STEPS.  (1) A CALL (FROM THE DRIVER PROGRAM FOR
CC          THIS UPWELLING NATURAL RADIATION MODEL) TO NCM SUBROUTINE
CC          CLOUDO WHICH READS DATA CARDS FOR THE STATISTICAL CLOUD SUB-
CC          MODEL AND  (2) REPLACEMENT OF THE CALL FROM THE NCM DRIVER TO
CC          THE NCM SUBROUTINE SCLOUD BY A SET OF CALLS AND OPERATIONS IN
CC          SUBROUTINE UPWELL WHICH, IN THEIR TOTALITY, ADAPT THE ROLE OF
CC          SUBROUTINE SCLOUD TO OUR SPECIAL NEEDS. A FLAG (CLDFLG), SET
CC          BY A READ STATEMENT, HAS BEEN INTRODUCED SO THAT NATURAL
CC          CLOUDS ARE IGNORED IF CLDFLG=0 AND ARE INCLUDED IF
CC          (A) CLDFLG=1 AND (B) THE ALTITUDE ABOVE THE SURFACE AT WHICH
CC          THE UPWELLING RADIATION IS COMPUTED IS AT LEAST 12 KM  (THE
CC          HIGHEST ALTITUDE OF THE TOP OF ANY OF THE STATISTICAL CLOUDS).
CCC
      READ (5,300) CLDFLG
      WRITE(6,318) CLDFLG
CC       * SET PARAMETERS IN PARAMS COMMON.
      INFIL = 5   $   IOFIL = 6
      ERAD = 6371.03
      DGTOR = PI / 180.   $   RTODG = 1.0 / DGTOR
CC       * NOTE THAT SUBROUTINE CLOUDO READS SEVEN CARDS, THE FIRST OF
CC          WHICH IS FOR MODE=1 .
      IF( CLDFLG.EQ.1.0 )  CALL CLOUDO(MODE)
CCC
CC * * *  CREATE DATASETS BN AND BI AND SET WORDS.
CC          WAVELENGTHS IN THESE TWO DATASETS ARE IN MICRONS FOR SAI AND
CC           IN CENTIMETERS FOR GRC.
      J = 0
  100 READ (5,320) ALAM1, ALAM2, W1, W2, LINT
C           NEGATIVE WAVELENGTH DENOTES END OF BANDS.
      IF( ALAM1 .LT. 0. )  GO TO 105
      J = J + 1
C           DIMENSIONING LIMITS ALLOWED NUMBER OF BANDS TO 5 .
      IF( J .GT. 5 )  GO TO 105
      NWAVE(J) = LINT
      IF( ALAM1 .EQ. 0. )  GO TO 102
C           BAND-LIMIT WAVELENGTHS ARE INPUT.
      ALMIN = AMIN1 ( ALAM1, ALAM2 )
      ALMAX = AMAX1 ( ALAM1, ALAM2 )
```

```
C          CREATE THE 5-WORD DATASET-BN AND SET THE FIRST FOUR WORDS.      DRVUPW
      CALL CREATE ( 5, NBN )                                                DRVUPW
      BNLO  BN(NBN) = ALMIN                                                 DRVUPW
      BNHI  BN(NBN) = ALMAX                                                 DRVUPW
      WLO   BN(NBN) = 1.E+04/BNHI BN(NBN)                                   DRVUPW
      WHI   BN(NBN) = 1.E+04/BNLO BN(NBN)                                   DRVUPW
      DBN = ( BNHI BN(NBN) - BNLO BN(NBN) ) / FLOAT(LINT)                   DRVUPW
      WRITE(6,303) ALMIN, ALMAX, FLOAT(LINT), DBN,                          DRVUPW
     *       .   WLO BN(NBN), WHI BN(NBN)                                   DRVUPW
C                                                                           DRVUPW
C          LOOP DO-101 IS PATTERNED AFTER LOOP DO-700 IN GRC'S              DRVUPW
C          PROGRAM ATKGEN.                                                  DRVUPW
      DO 101 I=1,LINT                                                       DRVUPW
C          CREATE THE 8-WORD DATASET-BI AND SET THE FIRST SEVEN WORDS.     DRVUPW
      CALL CREATE ( 8, NBI )                                                DRVUPW
      BNLO  BI(NBI) = BNLO BN(NBN) + FLOAT(I-1)*DBN                         DRVUPW
      BNHI  BI(NBI) = BNLO BI(NBI) + DBN                                    DRVUPW
      WLO   BI(NBI) = 1.E+04/BNHI BI(NBI)                                   DRVUPW
      WHI   BI(NBI) = 1.E+04/BNLO BI(NBI)                                   DRVUPW
      BKGND BI(NBI) = 0.                                                    DRVUPW
      TRANS BI(NBI) = 0.                                                    DRVUPW
      TFLAG BI(NBI) = 0.                                                    DRVUPW
      IF( I .EQ. 1 )  TFLAG BI(NBI) = 1.                                    DRVUPW
      IF( I .GT. 1  .AND.  I .EQ. LINT )  TFLAG BI(NBI) = 2.                DRVUPW
C                                                                           DRVUPW
C          SET WORD-5 OF DATASET-BN, LINRV BN(NBN), WHICH IS A POINTER TO DRVUPW
C          THE LIST HEADER FOR THE DATASET-BI.  THERE IS, OF COURSE, A     DRVUPW
C          DIFFERENT POINTER FOR EACH DATASET-BN.  USE OF SUBROUTINE       DRVUPW
C          PUTBOT MEANS THAT THE HIGHEST WAVELENGTH (OR LOWEST WAVENUMBER DRVUPW
C          ) IS ON THE BOTTOM OF THE LIST.                                  DRVUPW
      CALL PUTBOT ( LINRV BN(NBN), NBI )                                    DRVUPW
  101 CONTINUE                                                              DRVUPW
C                                                                           DRVUPW
C          GET LBAND, THE POINTER TO THE LIST HEADER FOR DATASET-BN.  IF   DRVUPW
C          THE INPUT BANDS ARE ORDERED WITH RESPECT TO INCREASING VALUES   DRVUPW
C          OF ALAM2 (ASSUMING ALAM2 .GT. ALAM1), THEN USE OF SUBROUTINE    DRVUPW
C          PUTBOT MEANS THAT THE HIGHEST WAVELENGTH (OR LOWEST WAVENUMBER DRVUPW
C          ) IS ON THE BOTTOM OF THE LIST.                                  DRVUPW
C                                                                           DRVUPW
      CALL PUTBOT ( LBAND, NBN )                                            DRVUPW
      GO TO 100                                                             DRVUPW
CC                                                                          DRVUPW
C          BAND-LIMIT WAVENUMBERS ARE INPUT.                                DRVUPW
  102 WMIN = AMIN1 ( W1, W2 )                                               DRVUPW
      WMAX = AMAX1 ( W1, W2 )                                               DRVUPW
      ALMIN = 1.E+04/WMAX                                                   DRVUPW
      ALMAX = 1.E+04/WMIN                                                   DRVUPW
C          CREATE THE 5-WORD DATASET-BN AND SET THE FIRST FOUR WORDS.      DRVUPW
      CALL CREATE ( 5, NBN )                                                DRVUPW
      BNLO  BN(NBN) = ALMIN                                                 DRVUPW
      BNHI  BN(NBN) = ALMAX                                                 DRVUPW
      WLO   BN(NBN) = WMIN                                                  DRVUPW
      WHI   BN(NBN) = WMAX                                                  DRVUPW
      DWN = ( WHI BN(NBN) - WLO BN(NBN) ) / FLOAT(LINT)                     DRVUPW
      WRITE(6,303) ALMIN, ALMAX, WLO BN(NBN), WHI BN(NBN),                  DRVUPW
     *             FLOAT(LINT), DWN                                         DRVUPW
C                                                                           DRVUPW
```

```
C          LOOP DO-103 IS PATTERNED AFTER LOOP DO-702 IN GRC'S              DRVUPW
C          PROGRAM ATKGEN.                                                  DRVUPW
      DO 103 I=1,LINT                                                       DRVUPW
C          CREATE THE 8-WORD DATASET-BI AND SET THE FIRST SEVEN WORDS.      DRVUPW
      CALL CREATE ( 8, NBI )                                                DRVUPW
      WLO   BI(NBI) = WLO BN(NBN) + FLOAT(I-1)*DWN                          DRVUPW
      WHI   BI(NBI) = WLO BI(NBI) + DWN                                     DRVUPW
      BNLO  BI(NBI) = 1.E+04/WHI BI(NBI)                                    DRVUPW
      BNHI  BI(NBI) = 1.E+04/WLO BI(NBI)                                    DRVUPW
      BKGND BI(NBI) = 0.                                                    DRVUPW
      TRANS BI(NBI) = 0.                                                    DRVUPW
      TFLAG BI(NBI) = 0.                                                    DRVUPW
      IF( I .EQ. 1 )  TFLAG BI(NBI) = 2.                                    DRVUPW
      IF( I .GT. 1  .AND.  I .EQ. LINT )  TFLAG BI(NBI) = 1.                DRVUPW
C                                                                           DRVUPW
C          SET WORD-5 OF DATASET-BN.  USE OF PUTTOP MEANS THAT THE LOWEST   DRVUPW
C          WAVENUMBER (OR HIGHEST WAVELENGTH) IS ON THE BOTTOM OF THE       DRVUPW
C          LIST.                                                            DRVUPW
      CALL PUTTOP ( LINRV BN(NBN), NBI )                                    DRVUPW
  103 CONTINUE                                                              DRVUPW
C                                                                           DRVUPW
C          GET LHV (LBAND) FOR DATASET-BN.  IF THE INPUT BANDS ARE          DRVUPW
C          ORDERED WITH RESPECT TO INCREASING VALUES OF W1 (ASSUMING W2     DRVUPW
C          .GT. W1), THEN USE OF PUTTOP MEANS THAT THE LOWEST WAVENUMBER    DRVUPW
C          (OR HIGHEST WAVELENGTH) IS ON THE BOTTOM OF THE LIST.            DRVUPW
      CALL PUTTOP ( LBAND, NBN )                                            DRVUPW
      GO TO 100                                                             DRVUPW
  105 NBANDS = MINO( J, 5 )                                                 DRVUPW
CCC                                                                         DRVUPW
CC * * *   COMPUTE BAND-MODEL PARAMETERS AFTER SETTING PARAMETERS IN        DRVUPW
CC         XYZCOM AND OPTION COMMONS NEEDED FOR SUBROUTINE TRANSB.          DRVUPW
      ITMTE = 2   $   LTMTE = 3                                             DRVUPW
      READ (5,301) TRNSOPT                                                  DRVUPW
      WRITE(6,304) TRNSOPT                                                  DRVUPW
      CALL TRANSB ( LBAND )                                                 DRVUPW
CCC                                                                         DRVUPW
CC * * *   INITIALIZE ATMOSPHERIC SHELLS AFTER SETTING PARAMETER IN         DRVUPW
CC         XYZCOM COMMON.                                                   DRVUPW
      READ (5,300) FACT                                                     DRVUPW
      WRITE(6,302) FACT                                                     DRVUPW
      CALL SHELLS                                                           DRVUPW
CCC                                                                         DRVUPW
CC * * *   PREPARE TO CALL SUBROUTINE UPWELL BY SETTING NEEDED PARAMETERS   DRVUPW
CC         IN VARIOUS COMMONS.                                              DRVUPW
CC       * SET PARAMETERS IN AEROK COMMON.                                  DRVUPW
      READ (5,315) KVIS, KPTYPE                                             DRVUPW
      WRITE(6,317) KVIS, KPTYPE                                             DRVUPW
CC       * SET PARAMETER IN OPTINI COMMON.                                  DRVUPW
      READ (5,301) RADSW                                                    DRVUPW
      WRITE(6,305) RADSW                                                    DRVUPW
CC       * SET PARAMETERS IN UPWELS COMMON.                                 DRVUPW
      UPWALT = 0.0   $   UPWLON = PLON   $   UPWLAT = PLAT                  DRVUPW
      READ (5,315) NNADIR, NAZI                                             DRVUPW
      WRITE(6,319) NNADIR, NAZI                                             DRVUPW
CC       * SET PARAMETER IN XYZCOM COMMON.  NOTE NMOLS IS KNOWN AS NMOLS    DRVUPW
CC         IN SUBROUTINE ATMRAD BUT AS NSPEC IN SUBROUTINE TRANS.           DRVUPW
      NMOLS = 10                                                            DRVUPW
```

```
CC        * SET TWO OF THE PARAMETERS FOR SUBROUTINE UPWELL ARGUMENT  LIST
      READ (5,315) MSM
      WRITE(6,321) MSM
      SPCULR = .FALSE.
      IF( MSM .EQ. 2 )  READ (5,301) SPCULR
      WRITE(6,322) SPCULR
CCC
CC * * *  LOOP OVER BROAD BANDS WITH CALLS TO SUBROUTINES SETALT AND
CC          UPWELL.  THE PORTION OF THIS LOOP THROUGH THE CALL TO
CC          SUBROUTINE UPWELL (BUT WITHOUT THE SUBSEQUENT PRINT) IS
CC          PATTERNED AFTER THAT IN THE GRC PROGRAM OLOOK.
CC          USE OF PREV IN STATEMENT LABELS 106 AND 107 MEANS THAT BOTH
CC          BANDS AND BAND INTERVALS ARE BEING PROCESSED IN ORDER OF
CC          INCREASING WAVENUMBERS.
C           ON THE FIRST CALL TO SUBROUTINE PREV, THE INPUT VALUE OF
C           LHBAND IS EQUAL TO LBAND, THE (1-FIELD) POINTER TO THE (2-
C           FIELD) LIST HEADER FOR DATASET-BN, WHEREAS THE RETURN VALUE OF
C           LHBAND IS THE LAST (3-FIELD) LINK-WORD FOR DATASET-BN AND THE
C           RETURN VALUE OF NBN, THE DATASET-BN INDEX (OR POINTER), IS THE
C           Q-ARRAY ADDRESS OF THE FIRST (NOT ZEROTH) WORD OF DATASET-BN.
C           SUCCESSIVE CALLS TO PREV RETURN SUCCESSIVE LINK WORDS AS THE
C           VARIABLE LHBAND UNTIL THE LAST CALL (WHICH RETURNS ZERO FOR
C           THE DATASET INDEX NBN) RETURNS THE (2-FIELD) LIST HEADER AS
C           THE WORD FOR LHBAND.
      J = 0
      LHBAND = LBAND
  106 CALL PREV ( LHBAND, NBN )
      IF( NBN .EQ. 0 )  GO TO 110
      J = J + 1
      IF( J .GT. 5 )  GO TO 110
      I = 0
C           LBINT IS SAVED FOR CALL TO SUBROUTINE UPWELL.
      LBINT = LINRV BN(NBN)
      LINT  = LINRV BN(NBN)
  107 CALL PREV ( LINT, NBI )
      IF( NBI .EQ. 0 )  GO TO 108
      I = I + 1
      IF( I .GT. 10 )  GO TO 108
      WW(I) = 0.5*( WHI BI(NBI) + WLO BI(NBI) )
      DW(I) =  ABS( WHI BI(NBI) - WLO BI(NBI) )
C           ALAM(I) AND DLAM(I) ARE USED ONLY IN PRINTING THE RESULTS SO
C           THAT BOTH WAVENUMBERS AND WAVELENGTHS ARE READILY AVAILABLE.
      ALAM(I) = 1.E+04/WW(I)
      DLAM(I) = ABS( BNHI BI(NBI) - BNLO BI(NBI) )
      GO TO 107
  108 CONTINUE
      NWAVE(J) = MINO( I, 10 )
      NWAVEJ = NWAVE(J)
CC        * SET ARGUMENT-LIST PARAMETERS FOR SUBROUTINE SETALT.
      ALMAX = 1.E+04/( WW(1)-0.5*DW(1) )
      ALMIN = 1.E+04/( WW(NWAVEJ)+0.5*DW(NWAVEJ) )
      ALMIN = AMAX1 ( ALMIN, 2.0 )
      ALMAX = AMIN1 ( ALMAX, 5.0 )
      CALL SETALT ( ALMIN, ALMAX, J )
CC          NOTE THAT SUBROUTINE SETALT OUTPUTS, THROUGH UPWELS COMMON,
CC          NALT(J) AND ZKM(II,J).
CC        * NOW READY TO CALL SUBROUTINE UPWELL.
```

```
      REWIND 8
      CALL UPWELL ( MSM, DD, WW, DW, SPCULR, LBINT, J )
CC
CC    * * PRINT RESULTS.
      REWIND 8
      WRITE(6,402)
  402 FORMAT (1H1,42X,*UPWELLING RADIANCE RESULTS FROM PROGRAM DRVUPW*/1
     $X,48X,33HIN UNITS OF WATTS/(CM**2 SR CM-1))
      WRITE(6,401) J, NWAVEJ
  401 FORMAT (1H0,5X,8HJ=JBAND=,I2,14H      NWAVE(J)=,I3)
      WRITE(6,406) (WW(L),DW(L),ALAM(L),DLAM(L),L=1,NWAVEJ)
  406 FORMAT (*0   FOR THE SPECTRAL QUANTITIES WE HAVE (FOR L=1,NWAVEJ)
     $THE QUARTETS WW(L), DW(L), ALAM(L), AND DLAM(L) =*/(5X,1P8E12.4))
      WRITE (6,403)  MSM
  403 FORMAT (1H0,5X,5HMAT.=,I3)
      IC = 0
      ICC = 0
      NALTJ = NALT(J)
      DO 475 II=1,NALTJ
      WRITE(6,409)  ZKM(II,J)
  409 FORMAT (1H0,5X,10HALTITUDE =,F7.2,4H  KM)
      DO 470 JJ=1,NNADIR
      WRITE(6,404) JJ
  404 FORMAT (1H0,1X,*NADIR J = *I2)
      READ(8)   ( ( UPRAD(KK,LL),KK=1,NAZI ), LL=1,NWAVEJ )
      WRITE(6,405)
  405 FORMAT (4X,*NO CLOUDS*/2X,21HAZIMUTH / WAVENUMBER..5X,10HUPRAD(K,L
     $))
CCC
      DO 480 KK=1,NAZI
      WRITE(6,407)   KK,    ( UPRAD(KK,LL),LL=1,NWAVEJ )
  407 FORMAT (2X, I5 ,1P10E12.4)
  480 CONTINUE
CCC
      IF( (CLDFLG .EQ. 0.0) .OR. (ZKM(II,J) .LT. 12.0) )  GO TO 470
      READ(8)  (((R010(KK,LL),R025(KK,LL),R050(KK,LL),R090(KK,LL),
     $               R100(KK,LL)), KK=1,NAZI), LL=1,NWAVEJ)
      WRITE(6,605)
  605 FORMAT (1H0,3X,*WITH CLOUDS*/2X,21HAZIMUTH / WAVENUMBER..5X,64HARC
     $V(K,L), R010(K,L), R025(K,L), R050(K,L), R090(K,L), R100(K,L))
CCC
      IF ( JJ .EQ. 1 )  ICC = ICC + 1
      DO 680 KK=1,NAZI
      WRITE(6,6070)  KK,(ARCVA(ICC,JJ,LL),LL=1,NWAVEJ)
      WRITE(6,6071)  KK,       (R010(KK,LL),LL=1,NWAVEJ)
      WRITE(6,6072)  KK,       (R025(KK,LL),LL=1,NWAVEJ)
      WRITE(6,6073)  KK,       (R050(KK,LL),LL=1,NWAVEJ)
      WRITE(6,6074)  KK,       (R090(KK,LL),LL=1,NWAVEJ)
      WRITE(6,6075)  KK,       (R100(KK,LL),LL=1,NWAVEJ)
 6070 FORMAT (1X, I4 , 6H ARCV , 1P10E12.4)
 6071 FORMAT (1X, I4 , 6H R010 , 1P10E12.4)
 6072 FORMAT (1X, I4 , 6H R025 , 1P10E12.4)
 6073 FORMAT (1X, I4 , 6H R050 , 1P10E12.4)
 6074 FORMAT (1X, I4 , 6H R090 , 1P10E12.4)
 6075 FORMAT (1X, I4 , 6H R100 , 1P10E12.4)
  680 CONTINUE
  470 CONTINUE
```

```
CCC
      WRITE(6,413)
  413 FORMAT (1H0,1X,*AZIMUTH-AVERAGED RESULTS*/3X,*NO CLOUDS*/2X,21H  N
     $ADIR / WAVENUMBER.,5X,13HUPRADA(I,J,L))
      DO 465 JJ=1,NNADIR
      WRITE(6,411)   JJ,    ( UPRADA(II,JJ,LL),LL=1,NWAVEJ )
  411 FORMAT (2X, I5 ,1P10E12.4)
  465 CONTINUE
CCC
      IF( (CLDFLG .EQ. 0.0) .OR. (ZKM(II,J) .LT. 12.0) )  GO TO 475
      WRITE(6,613)
  613 FORMAT (1H0,3X,*WITH CLOUDS*/2X,21H  NADIR / WAVENUMBER.,5X,82HARC
     $VA(I,J,L), R010A(I,J,L), R025A(I,J,L), R050A(I,J,L), R090A(I,J,L),
     $ R100A(I,J,L))
      IC = IC + 1
      DO 665 JJ=1,NNADIR
      WRITE(6,6110)  JJ,      (ARCVA(IC,JJ,LL),LL=1,NWAVEJ)
      WRITE(6,6111)  JJ,      (R010A(IC,JJ,LL),LL=1,NWAVEJ)
      WRITE(6,6112)  JJ,      (R025A(IC,JJ,LL),LL=1,NWAVEJ)
      WRITE(6,6113)  JJ,      (R050A(IC,JJ,LL),LL=1,NWAVEJ)
      WRITE(6,6114)  JJ,      (R090A(IC,JJ,LL),LL=1,NWAVEJ)
      WRITE(6,6115)  JJ,      (R100A(IC,JJ,LL),LL=1,NWAVEJ)
 6110 FORMAT (1X, I4 , 6H ARCVA,1P10E12.4)
 6111 FORMAT (1X, I4 , 6H R010A,1P10E12.4)
 6112 FORMAT (1X, I4 , 6H R025A,1P10E12.4)
 6113 FORMAT (1X, I4 , 6H R050A,1P10E12.4)
 6114 FORMAT (1X, I4 , 6H R090A,1P10E12.4)
 6115 FORMAT (1X, I4 , 6H R100A,1P10E12.4)
  665 CONTINUE
  475 CONTINUE
CCC
      WRITE(6,414)
  414 FORMAT (1H0,10X,*AZIMUTH- AND NADIR-AVERAGED RESULTS VS ALTITUDE*)
      WRITE(6,415)
  415 FORMAT (1H0,1X,*NO CLOUDS*/2X,17HALT / WAVENUMBER.,5X,*UPRADN(I,L,
     $J)*)
      DO 490 II=1,NALTJ
      WRITE(6,417)  ZKM(II,J),   ( UPRADN(II,LL,J),LL=1,NWAVEJ )
  417 FORMAT (2X,F7.2,1P10E12.4)
  490 CONTINUE
CCC
      IF( CLDFLG .EQ. 0.0 )  GO TO 109
      IC = 0
      WRITE(6,615)
  615 FORMAT (1H0,1X,*WITH CLOUDS*/2X,17HALT / WAVENUMBER.,5X,*ARCVN(I,L
     $), R010N(I,L), R025N(I,L), R050N(I,L), R090N(I,L), R100N(I,L)*)
      DO 690 II=1,NALTJ
      IF( ZKM(II,J) .LT. 12.0 )  GO TO 690
      IC = IC + 1
      WRITE(6,6170) ZKM(II,J), ( ARCVN(IC,LL),LL=1,NWAVEJ )
      WRITE(6,6171) ZKM(II,J), ( R010N(IC,LL),LL=1,NWAVEJ )
      WRITE(6,6172) ZKM(II,J), ( R025N(IC,LL),LL=1,NWAVEJ )
      WRITE(6,6173) ZKM(II,J), ( R050N(IC,LL),LL=1,NWAVEJ )
      WRITE(6,6174) ZKM(II,J), ( R090N(IC,LL),LL=1,NWAVEJ )
      WRITE(6,6175) ZKM(II,J), ( R100N(IC,LL),LL=1,NWAVEJ )
 6170 FORMAT (1X, F6.2 , 6H ARCVN,1P10E12.4)
 6171 FORMAT (1X, F6.2 , 6H R010N,1P10E12.4)
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 6172 FORMAT (1X, F6.2 , 6H R025N,1P10E12.4)
 6173 FORMAT (1X, F6.2 , 6H R050N,1P10E12.4)
 6174 FORMAT (1X, F6.2 , 6H R090N,1P10E12.4)
 6175 FORMAT (1X, F6.2 , 6H R100N,1P10E12.4)
  690 CONTINUE
  109 GO TO 106
  110 CONTINUE
  200 STOP
CC
  300 FORMAT ( 8E10.0 )
  301 FORMAT(L10)
  302 FORMAT (1H0,1X, 6HFACT =,F6.2)
  303 FORMAT ( 1P 6E15.5 )
  304 FORMAT (1H0,1X, 9HTRNSOPT =,L2)
  305 FORMAT (1H0,1X, 7HRADSW =,L2)
  315 FORMAT ( 3I10, 3E10.0 )
  316 FORMAT (1H0,1X, 6HIYRS =,I3,7X,7HIMONS =,I3,7X,7HIDAYS =,I3,7X,4HZ
     $T =,F6.3,4X,5HGCO =,F8.3,3X,5HGLO =,F8.3)
  317 FORMAT (1H0,1X, 6HKVIS =,I2,7X,8HKPTYPE =,I2)
  318 FORMAT (1H0,1X, 8HCLDFLG =,F3.0)
  319 FORMAT (1H0,1X, 8HNNADIR =,I2,7X,6HNAZI =,I2)
  320 FORMAT (4E10.0, I10)
  321 FORMAT (1H0,1X, 5HMSM =,I2)
  322 FORMAT (1H0,1X, 8HSPCULR =,L2)
  323 FORMAT (1H0,1X,50Z5)
      END
```

```
      FUNCTION ACCUM( ITYPE, X1, X2, F1, F2, A, B )
C
CLJ      FUNCTION ACCUM INTEGRATES BETWEEN X=A AND X=B  A FUNCTION F(X)
CLJ      GIVEN AT TWO POINTS X1 AND X2 BY LINEAR, LOGARITHMIC, OR
CLJ      POWER-LAW INTERPOLATION, CORRESPONDING TO ITYPE=1,2,3 ,
CLJ      RESPECTIVELY.  LINEAR INTERPOLATION IS ASSUMED IN CASE THE
CLJ      OTHER METHODS WOULD FAIL.
C
      GO TO ( 1, 2, 3 ), ITYPE
  1   ACCUM = .5 / ( X2 - X1 ) * ( F2 * (( B - X1 )**2 - ( A - X1 )**2 )
     1        - F1 * (( B - X2 )**2 - ( A - X2 )**2 ))
      RETURN
  2   IF ( F1 * F2 .LE. 0. ) GO TO 1
      IF ( ABS( 1. - F1 / F2 ) .LT. 0.01 ) GO TO 1
      ALNR = ALOG( F2 / F1 )
      ACCUM = F1 / ALNR * ( EXP( ( B - X1 ) / ( X2 - X1 ) * ALNR )  -
     1          EXP( ( A - X1 ) / ( X2 - X1 ) * ALNR )) * ( X2 - X1 )
      RETURN
  3   IF ( X1 * X2 .LE. 0.  .OR.  F1 * F2 .LE. 0. ) GO TO 1
      EVAL = ALOG( F2 / F1 ) / ALOG( X2 / X1 )
      IF ( ABS( EVAL ) .GT. 10. ) GO TO 1
      ACCUM = F1 / (( EVAL + 1. ) * X1**EVAL ) * ( B**( EVAL + 1. )  -
     1        A**( EVAL + 1. ) )
      RETURN
      END
```

```
      SUBROUTINE AEROSOL( HCM,LAMDA,XKSCT,XKABS,GBAR )                  AERSOL
CCC                                                                     AERSOL
C     SUBROUTINE AERSOL COMPUTES ATTENUATION COEFFICIENTS FOR           AERSOL
C     SCATTERING AND ABSORPTION AND THE ASYMMETRY FACTOR (AVERAGE       AERSOL
C     COSINE OF THE SCATTERING ANGLE) DUE TO ATMOSPHERIC AEROSOLS.      AERSOL
C     THIS PROGRAM IS BASED DIRECTLY ON THE WORK OF E.P. SHETTLE AND    AERSOL
C     R.W. FENN OF AFGL AND USES A PORTION OF MATERIAL WHICH WILL       AERSOL
C     APPEAR IN A FORTHCOMING DOCUMENT (AFGL-TR-77-XXXX), ''MODELS OF   AERSOL
C     THE ATMOSPHERIC AEROSOLS AND THEIR OPTICAL PROPERTIES'' BY E.P.   AERSOL
C     SHETTLE AND R.W. FENN.                                            AERSOL
C     IN SUBROUTINE AERSOL, THE WAVELENGTH REGION IS RESTRICTED TO 2-5  AERSOL
C     MICRONS AND PROPERTIES ARE PRESENTED FOR AVERAGE SEASONAL CONDI-  AERSOL
C     TIONS ONLY AND FOR ALTITUDES LESS THAN 100 KM.  THE ALTITUDE      AERSOL
C     REGION FROM SEA LEVEL TO 100 KM IS DIVIDED INTO FOUR REGIONS...   AERSOL
C          A    BOUNDARY LAYER          0-2 KM                          AERSOL
C          B    TROPOSPHERE             2-9 KM                          AERSOL
C          C    STRATOSPHERE            9-30 KM                         AERSOL
C          D    UPPER ATMOSPHERE        30-100 KM                       AERSOL
C     IN THE TROPOSPHERE AND THE BOUNDARY LAYER REGION, PROPERTIES ARE  AERSOL
C     COMPUTED FOR ONE OF FIVE VISIBILITY RANGES (50,23,10,5,2 KM) AND  AERSOL
C     IN THE BOUNDARY LAYER, FOR ONE OF THREE TERRAIN TYPES (RURAL,     AERSOL
C     URBAN, AND MARITIME).  IN THE STRATOSPHERE A CONTRIBUTION FROM    AERSOL
C     VOLCANIC AEROSOLS IS ALSO ADDED TO THAT FROM BACKGROUND AEROSOLS. AERSOL
C     THE ABSORPTION COEFFICIENTS ARE COMPUTED AS A PRODUCT OF A SCALE  AERSOL
C     FACTOR (EQUAL TO THE AEROSOL EXTINCTIONS AT 0.55 MICRONS) FOR THE AERSOL
C     DIFFERENT MODELS TIMES ATTENUATION COEFFICIENTS FOR THE           AERSOL
C     SCATTERING, ABSORPTION AND THE ASYMMETRY FACTOR AS FUNCTIONS OF   AERSOL
C     WAVELENGTH NORMALIZED TO THE EXTINCTION COEFFICIENT AT 0.55       AERSOL
C     MICRONS.                                                          AERSOL
CCC                                                                     AERSOL
CLJ                                                                     AERSOL
CLJ   VERSION 1 OF THE VISIDYNE-SUPPLIED AERSOL ROUTINE WAS RECEIVED ON AERSOL
CLJ   10/13/77.  WE HAVE LEFT GBAR, THE ASYMMETRY FACTOR, IN THE ARGU-  AERSOL
CLJ   MENT LIST BUT HAVE COMMENTED OUT THE STATEMENTS WHICH EVALUATE    AERSOL
CLJ   GBAR BECAUSE OUR TREATMENT OF AEROSOL TRANSMITTANCE DOES NOT USE  AERSOL
CLJ   IT.  OUR TREATMENT PROVIDES FOR ATTENUATION BY ABSORPTION AND     AERSOL
CLJ   SCATTERING OUT OF THE BEAM BUT FOR NO SCATTERING INTO THE BEAM.   AERSOL
CLJ   IT WAS OUR UNDERSTANDING THAT G.E.TEMPO (EWING, 10/18/77) ALSO    AERSOL
CLJ   PLANNED TO ACCOUNT ONLY FOR SINGLE SCATTERING OF AEROSOLS (AS     AERSOL
CLJ   OPPOSED TO ACCOUNTING FOR MULTIPLE SCATTERING WITHIN NUCLEAR      AERSOL
CLJ   CLOUDS).  ON THIS BASIS WE INTEGRATED SUBROUTINE AERSOL INTO OUR  AERSOL
CLJ   UPWELLING NATURAL RADIATION MODEL AND INTERFACED IT WITH THE GET  AERSOL
CLJ   TRANSMISSION MODEL.                                               AERSOL
CLJ                                                                     AERSOL
CLJ   OUR COPY OF VERSION 2 OF AERSOL IS DATED 2/13/78.  WE HAVE UPDATED AERSOL
CLJ   OUR VERSION 1 WITH THE SUBSTANTIVE CHANGES IN VERSION 2 BUT DID   AERSOL
CLJ   NOT INCLUDE THE NONSUBSTANTIVE CHANGES IN SPELLINGS.              AERSOL
CLJ                                                                     AERSOL
CLJ   NOTE...WE HAVE ALSO MADE CORRECTIONS PERTAINING TO THE SEARCHING  AERSOL
CLJ          OF THE WAVELENGTH ARRAY IN DO-LOOPS  6, 7, 9, AND 10.      AERSOL
CLJ          IF LAMDA=WAVE(12)=5.0 MICRONS ERRONEOUS VALUES OF XKSCT    AERSOL
CLJ          AND XKABS WOULD BE RETURNED TO THE CALLING PROGRAM.        AERSOL
CLJ                                                                     AERSOL
CLJ   VERSION 3  (08/29/78)  PROVIDES...                                AERSOL
CLJ     1. THE ALTITUDE IN THE ARGUMENT LIST TO BE IN CENTIMETERS       AERSOL
CLJ        INSTEAD OF KILOMETERS.                                       AERSOL
CLJ     2. THE SCATTERING AND ABSORPTION ATTENUATION COEFFICIENTS TO BE AERSOL
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                                                                   AERSOL
CLJ        IN 1/CM INSTEAD OF 1/KM.                                AERSOL
CLJ    VERSION 4 (01/13/79) PROVIDES...                            AERSOL
CLJ      3. A TEST (2.0 .LE. LAMDA .LE. 5.0) FOR NONZERO VALUES OF THE  AERSOL
CLJ         OUTPUT PARAMETERS.                                     AERSOL
CLJ    NOTE...REVISED REPORT VI-401, THE COMPUTER MODEL FOR ATMOSPHERIC  AERSOL
CLJ           AERSOL OPTICAL PROPERTIES, BY C.H. HUMPHREY, M.E. GARDNER,  AERSOL
CLJ           E.P. SHETTLE, AND R.W. FENN, JUNE 1978, WAS RECEIVED AT SAI  AERSOL
CLJ           13 DEC 78.  THE REVISED SUBROUTINE AERSOL IN THIS REPORT  AERSOL
CLJ           CORRECTS AN EARLIER ERROR WHICH LED TO ERRONEOUS RESULTS IF  AERSOL
CLJ           LAMDA=5.0 MICRONS.  HOWEVER, SAI HAS RETAINED ITS OWN  AERSOL
CLJ           EARLIER, DIFFERENT CORRECTION.  THE SAI CORRECTION ALSO  AERSOL
CLJ           ALLOWS THE SUBROUTINE TO COMPUTE NONZERO ANSWERS FOR  AERSOL
CLJ           LAMDA=2.0 MICRONS, IN CONTRAST WITH THE VI VERSION.  AERSOL
CLJ                                                                AERSOL
CLJ     INPUT PARAMETERS                                           AERSOL
CLJ        ARGUMENT LIST                                           AERSOL
CLJ                HCM = ALTITUDE ABOVE SEA LEVEL, CM              AERSOL
CLJ              LAMDA = WAVELENGTH, MICRONS                       AERSOL
CLJ                                                                AERSOL
CLJ        AEROK COMMON                                            AERSOL
CLJ               KVIS = VISIBILITY RANGE PARAMETER (FOR H=0-9 KM)  AERSOL
CLJ                    = 1  CORRESPONDS TO VISIBILITY RANGE = 50 KM  AERSOL
CLJ                    = 2  CORRESPONDS TO VISIBILITY RANGE = 23 KM  AERSOL
CLJ                    = 3  CORRESPONDS TO VISIBILITY RANGE = 10 KM  AERSOL
CLJ                    = 4  CORRESPONDS TO VISIBILITY RANGE =  5 KM  AERSOL
CLJ                    = 5  CORRESPONDS TO VISIBILITY RANGE =  2 KM  AERSOL
CLJ              KTYPE = TERRAIN PARAMETER (FOR H=0-2 KM)          AERSOL
CLJ                    = 1  TERRAIN = RURAL                        AERSOL
CLJ                    = 2  TERRAIN = URBAN                        AERSOL
CLJ                    = 3  TERRAIN = MARITIME                     AERSOL
CLJ                                                                AERSOL
CLJ     OUTPUT PARAMETERS                                          AERSOL
CLJ        ARGUMENT LIST                                           AERSOL
CLJ              XKSCT = SCATTERING ATTENUATION COEFFICIENT, 1/CM  AERSOL
CLJ              XKABS = ABSORPTION ATTENUATION COEFFICIENT, 1/CM  AERSOL
CLJ               GBAR = ASYMMETRY FACTOR                          AERSOL
CLJ                                                                AERSOL
CLJ     VARIABLES IN DATA ARRAYS                                   AERSOL
CLJ        WAVE(I)             = WAVELENGTH ARRAY FOR ABSORB, ASYM, AND  AERSOL
CLJ                              SCAT ARRAYS.                      AERSOL
CLJ                                                                AERSOL
CLJ        ABSOBA(I,J),...., = NORMALIZED ABSORPTION ATTENUATION   AERSOL
CLJ        ABSOBD(I)             COEFFICIENTS.                     AERSOL
CLJ        ASYMA(I,J),....   = ASYMMETRY FACTORS.                  AERSOL
CLJ        ASYMD(I)                                                AERSOL
CLJ        SCATA(I,J),....,  = NORMALIZED SCATTERING ATTENUATION   AERSOL
CLJ        SCATD(I)              COEFFICIENTS.                     AERSOL
CLJ        A,B,C, AND D          SIGNIFY ALTITUDE REGIONS.         AERSOL
CLJ        INDEX I               REFERS TO WAVELENGTH ARRAY.       AERSOL
CLJ        INDEX J               REFERS TO AEROSOL TYPE FOR H=0-2 KM.  AERSOL
CLJ        SCAL1(I,J),....,  = NORMALIZED SCALE FACTOR FOR ALTITUDE  AERSOL
CLJ        SCAL5(I)              REGIONS AS FOLLOWS...             AERSOL
CLJ                                1=A  BOUNDARY LAYER             AERSOL
CLJ                                2=B  TROPOSPHERE                AERSOL
CLJ                              3,4=C  STRATOSPHERE, VOLCANIC     AERSOL
CLJ                                5=D  UPPER ATMOSPHERE           AERSOL
CLJ              INDEX I REFERS TO ALTITUDE.  FOR REGIONS 1 AND 2, SCAL IS  AERSOL
CLJ              DOUBLY DIMENSIONED WITH J REFERRING TO VISIBILITY RANGE.  AERSOL
CLJ              (ALTITUDE VALUES SPECIFIED IN HITE ARRAY FOR REGION 1)  AERSOL
CLJ                                                                AERSOL
      DIMENSION HITE(4),SCAL1(4,5),WAVE(12),SCATA(12,3),ABSOBA(12,4),
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      1          SCATB(12),ABSOBB(12),          SCATC(12,2),              AERSOL   116
      2ABSOBC(12,2),            SCATD(12),ABSOBD(12),                     AERSOL   117
      3 SCAL2(8,2),SCAL3(22),SCAL4(22),SCAL5(15)                          AERSOL   118
CC     DIMENSION  ASYMA(12,4), ASYMB(12), ASYMC(12,2), ASYMD(12)          AERSOL   119
       COMMON/AEROK /  KVIS, KPTYPE                                       AEROKO     2
       REAL LAMDA                                                         AERSOL   121
       DATA(WAVE(I),I=1,12)/2.0,2.25,2.5,2.7,3.0,3.2,3.392,3.5,3.75,4.0,4 AERSOL   122
      1.5,5.0/                                                            AERSOL   123
       DATA(HITE(I),I=1,4)/0.0,1.0,1.5,2.0/                               AERSOL   124
       DATA(SCAL1(I,1),I=1,4)/6.95E-2,2.58E-2,1.61E-2,9.70E-3/            AERSOL   125
       DATA(SCAL1(I,2),I=1,4)/1.57E-1,9.90E-2,7.92E-2,6.21E-2/            AERSOL   126
       DATA(SCAL1(I,3),I=1,4)/3.72E-1,3.72E-1,3.72E-1,6.21E-2/            AERSOL   127
       DATA(SCAL1(I,4),I=1,4)/7.57E-1,7.57E-1,7.57E-1,6.21E-2/            AERSOL   128
       DATA(SCAL1(I,5),I=1,4)/1.88,1.88,1.88,6.21E-2/                     AERSOL   129
       DATA(SCATA(I,1),I=1,12)/1.312E-1,1.140E-1,1.016E-1,7.835E-2,       AERSOL   130
      18.330E-2,9.339E-2,9.251E-2,9.598E-2,9.394E-2,9.001E-2,             AERSOL   131
      28.011E-2,7.672E-2/                                                 AERSOL   132
       DATA(ABSOBA(I,1),I=1,12)/2.763E-2,2.894E-2,2.932E-2,6.559E-2,      AERSOL   133
      13.696E-2,2.046E-2,1.979E-2,1.583E-2,1.357E-2,1.465E-2,             AERSOL   134
      22.219E-2,2.033E-2/                                                 AERSOL   135
CC     DATA(ASYMA(I,1),I=1,12)/.715,.7306,.7459,.7863,.7714,.7491,.7456,  AERSOL   136
CC    1.7316,.7337,.7390,.7560,.7636/                                     AERSOL   137
       DATA(SCATA(I,2),I=1,12)/1.129E-1,9.833E-2,8.758E-2,7.286E-2,       AERSOL   138
      17.209E-2,7.572E-2,7.383E-2,7.500E-2,7.258E-2,6.939E-2,             AERSOL   139
      16.220E-2,5.900E-2/                                                 AERSOL   140
       DATA(ABSOBA(I,2),I=1,12)/1.339E-1,1.240E-2,1.157E-1,1.288E-1       AERSOL   141
      1,1.075E-1,9.346E-2,8.966E-2,8.610E-2,8.063E-2,7.739E-2,            AERSOL   142
      27.474E-2,6.824E-2/                                                 AERSOL   143
CC     DATA(ASYMA(I,2),I=1,12)/.649,.6609,.6730,.6900,.6937,.6894,        AERSOL   144
CC    1.6907,.6841,.6887,.6943,.7099,.7193/                               AERSOL   145
       DATA(SCATA(I,3),I=1,12)/7.159E-1,6.772E-1,6.093E-1,4.399E-1,       AERSOL   146
      13.271E-1,4.594E-1,5.670E-1,5.849E-1,5.645E-1,5.289E-1,             AERSOL   147
      24.520E-1,4.072E-1/                                                 AERSOL   148
       DATA(ABSOBA(I,3),I=1,12)/1.380E-2,1.062E-2,2.125E-2,9.134E-2,      AERSOL   149
      13.327E-1,2.208E-1,8.004E-2,4.164E-2,1.718E-2,1.985E-2,             AERSOL   150
      24.247E-2,3.660E-2/                                                 AERSOL   151
CC     DATA(ASYMA(I,3),I=1,12)/.7857,.7931,.8114,.8611,.8205,.7724        AERSOL   152
CC    1,.7448,.7413,.7475,.7530,.7630,.7645/                              AERSOL   153
       DATA (SCAL2(I,1),I=1,8) / 9.70E-3,9.25E-3,8.32E-3,7.08E-3,5.63E-3, AERSOL   154
      1 4.26E-3,2.39E-3,1.40E-3 /                                         AERSOL   155
       DATA (SCAL2(I,2),I=1,8) / 6.21E-2,3.09E-2,1.53E-2,7.08E-3,5.63E-3, AERSOL   156
      1 4.26E-3,2.39E-3,1.40E-3 /                                         AERSOL   157
       DATA(SCATB(I),I=1,12)/6.761E-2,5.005E-2,3.797E-2,2.650E-2,         AERSOL   158
      12.394E-2,2.350E-2,2.133E-2,2.174E-2,1.838E-2,1.564E-2,             AERSOL   159
      21.159E-2,8.487E-3/                                                 AERSOL   160
       DATA(ABSOBB(I),I=1,12)/1.092E-2,1.146E-2,1.157E-2,3.891E-2,        AERSOL   161
      11.589E-2,6.769E-3,6.481E-3,4.826E-3,4.017E-3,4.343E-3,             AERSOL   162
      27.013E-3,6.233E-3/                                                 AERSOL   163
CC     DATA(ASYMB(I),I=1,12)/.5828,.5688,.5551,.5427,.5305,               AERSOL   164
CC    1.5236,.5166,.5089,.4999,.4910,.4739,.4614/                         AERSOL   165
       DATA (SCAL3(I),I=1,22) / 1.40E-3,9.64E-4,7.57E-4,6.53E-4,5.70E-4,  AERSOL   166
      1 5.44E-4,5.19E-4,5.12E-4,5.13E-4,5.41E-4,5.37E-4,5.07E-4,          AERSOL   167
      2 4.28E-4,3.58E-4,2.71E-4,1.94E-4,1.41E-4,1.03E-4,7.87E-5,          AERSOL   168
      3 5.94E-5,4.66E-5,3.32E-5 /                                         AERSOL   169
       DATA (SCAL4(I),I=1,22) / 1.40E-3,1.62E-3,1.95E-3,2.33E-3,2.77E-3,  AERSOL   170
      1 2.89E-3,2.92E-3,2.74E-3,2.46E-3,2.10E-3,1.71E-3,1.35E-3,          AERSOL   171
      21.09E-3,8.60E-4,6.60E-4,5.15E-4,4.10E-4,3.20E-4,2.51E-4,           AERSOL   172
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     32.10E-4,1.24E-4,7.60E-5/
      DATA(SCATC(I,1),I=1,12)/4.055E-2,2.570E-2,1.560E-2,9.308E-2,
     16.321E-3,6.003E-3,6.274E-3,6.232E-3,5.103E-3,4.030E-3,
     22.420E-3,1.449E-3/
      DATA(ABSOBC(I,1),I=1,12)/1.282E-3,1.574E-3,2.894E-3,4.030E-3,
     15.878E-2,7.671E-2,8.300E-2,7.917E-2,6.019E-2,5.391E-2,
     24.552E-2,4.132E-2/
CC    DATA(ASYMC(I,1),I=1,12)/.3223,.2686,.2233,.1916,.1580,.1416,
CC   1.1299,.1242,.1108,.0983,.0780,.0629/
      DATA(SCATC(I,2),I=1,12)/1.353E-1,1.020E-1,7.792E-2,6.343E-2,
     15.126E-2,4.262E-2,3.761E-2,3.435E-2,2.913E-2,2.394E-2,
     21.775E-2,1.204E-2/
      DATA(ABSOBC(I,2),I=1,12)/1.019E-2,8.668E-3,8.429E-3,8.424E-3,
     19.493E-3,9.361E-3,7.431E-3,6.537E-3,4.879E-3,3.487E-3,
     23.186E-3,3 347E-3/
CC    DATA(ASYMC(I,2),I=1,12)/.5561,5255,.4958,.4729,.4401,.4196,.
CC   14015,.3915,.3699,.3490,.3125,.2773/
      DATA(SCATD(I),I=1,12)/4.822E-1,4.160E-1,3.574E-1,3.162E-1,
     12.645E-1,2.367E-1,2.147E-1,2.042E-1,1.845E-1,1.700E-1,
     21.509E-1,1.378E-1/
      DATA(ABSOBD(I),I=1,12)/6.161E-2,7.539E-2,8.943E-2,1.005E-1,
     11.161E-1,1.254E-1,1.331E-1,1.368E-1,1.435E-1,1.472E-1;
     21.463E-1,1.373E-1/
CC    DATA(ASYMD(I),I=1,12)/.6989,.7046,.7099,.7133,.7159,.7155,
CC   1.7134,.7116,.7058,.6986,.6827,.6687/
      DATA(SCAL5(I),I=1,15)/3.32E-5,1.65E-5,8.00E-6,4.02E-6,
     12.10E-6,1.09E-6,5.78E-7,3.05E-7,1.60E-7,6.95E-8,2.90E-8,
     21.20E-8,5.10E-9,2.15E-9,9.30E-10/
C
C
C
      IF( (LAMDA .GE. 2.0) .AND. (LAMDA .LE. 5.0) )  GO TO 1000
      WRITE(6,900) LAMDA
  900 FORMAT (1X,*SUBROUTINE AERSOL HAS BEEN ENTERED WITH LAMDA =*1PE12.
     $5*, WHICH IS OUTSIDE THE ALLOWED RANGE (2.0 TO 5.0 MICRONS).*/* ZE
     $RO-VALUES HAVE BEEN ASSIGNED TO THE OUTPUT PARAMETERS XKSCT AND XK
     $ABS.*)
      GO TO 11
 1000 CONTINUE
      H = 1.0E-05 * HCM
      IF(H .LT. 0.) STOP
      IF( H.GT.100. )  GO TO 11
      IF( H.GT. 30. )  GO TO  4
      IF( H.GT. 9.0 )  GO TO  3
      IF( H.GT. 2.0 )  GO TO  2
C
C ALTITUDE=0-2 KM
C
    1 DO 8 J=2,4
      IF( H.GE.HITE(J) )  GO TO 8
      COMON=(H-HITE(J-1))/(HITE(J)-HITE(J-1))
      ASCAL=SCAL1(J-1,KVIS)-(SCAL1(J-1,KVIS)-SCAL1(J,KVIS))*COMON
      GO TO 5
    8 CONTINUE
      IF( H.EQ.2.0 )  ASCAL = SCAL1(4,KVIS)
    5 DO 6 J=2,12
      IF( LAMDA.GT.WAVE(J) )  GO TO 6
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      COMON=(LAMDA-WAVE(J-1))/(WAVE(J)-WAVE(J-1))
      XKSCT=SCATA(J-1,KPTYPE)-(SCATA(J-1,KPTYPE)-SCATA(J,KPTYPE))*COMON
      XKABS=ABSOBA(J-1,KPTYPE)-(ABSOBA(J-1,KPTYPE)-ABSOBA(J,KPTYPE))
     1*COMON
CC    GBAR=ASYMA(J-1,KPTYPE)-(ASYMA(J-1,KPTYPE)-ASYMA(J,KPTYPE))*COMON
      GO TO 100
    6 CONTINUE
C
C ALTITUDE=2-9 KM
C
    2 IH=H-1.0
      HI=IH+1
      J = 2
      IF( KVIS.EQ.1 )  J = 1
      IF( H.NE.9.0 )  GO TO 12
      ASCAL = SCAL2(6,J)
      GO TO 13
   12 ASCAL = SCAL2(IH,J)-(SCAL2(IH,J)-SCAL2(IH+1,J))*(H-HI)
   13 DO 7 J=2,12
      IF( LAMDA.GT.WAVE(J) )  GO TO 7
      COMON=(LAMDA-WAVE(J-1))/(WAVE(J)-WAVE(J-1))
      XKSCT=SCATB(J-1)-(SCATB(J-1)-SCATB(J))*COMON
      XKABS=ABSOBB(J-1)-(ABSOBB(J-1)-ABSOBB(J))*COMON
CC    GBAR=ASYMB(J-1)-(ASYMB(J-1)-ASYMB(J))*COMON
      GO TO 100
    7 CONTINUE
C
C ALTITUDE=9-30 KM
C
    3 IH=H-8.0
      HI=IH+8
      IF( H.NE.30. )  GO TO 14
      FBG = SCAL3(22)
      VOLC = SCAL4(22)
      GO TO 15
   14 FBG = SCAL3(IH)-(SCAL3(IH)-SCAL3(IH+1))*(H-HI)
      VOLC=SCAL4(IH)-(SCAL4(IH)-SCAL4(IH+1))*(H-HI)
   15 DO 9 J=2,12
      IF( LAMDA.GT.WAVE(J) )  GO TO 9
      COMON=(LAMDA-WAVE(J-1))/(WAVE(J)-WAVE(J-1))
      XKSCT1=SCATC(J-1,1)-(SCATC(J-1,1)-SCATC(J,1))*COMON
      XKSCT2=SCATC(J-1,2)-(SCATC(J-1,2)-SCATC(J,2))*COMON
      XKABS1=ABSOBC(J-1,1)-(ABSOBC(J-1,1)-ABSOBC(J,1))*COMON
      XKABS2=ABSOBC(J-1,2)-(ABSOBC(J-1,2)-ABSOBC(J,2))*COMON
      XKSCT=XKSCT1*FBG+XKSCT2*VOLC
      XKABS=XKABS1*FBG+XKABS2*VOLC
CC    GBAR1=ASYMC(J-1,1)-(ASYMC(J-1,1)-ASYMC(J,1))*COMON
CC    GBAR2=ASYMC(J-1,2)-(ASYMC(J-1,2)-ASYMC(J,2))*COMON
CC    GBAR=(XKSCT1*GBAR1+XKSCT2*GBAR2)/(XKSCT1+XKSCT2)
      GO TO 105
    9 CONTINUE
C
C ALTITUDE IS GREATER THAN 30 KM
C
    4 IH=((H-30.0)/5.0)+1.01
      HI=(IH*5)+25
      IF( H.NE.100. )  GO TO 16
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      ASCAL = SCAL5(15)
      GO TO 17
   16 ASCAL = SCAL5(IH)-(SCAL5(IH)-SCAL5(IH+1))*(H-HI)/5.0
   17 DO 10 J=2,12
      IF( LAMDA.GT.WAVE(J) )  GO TO 10
      COMON=(LAMDA-WAVE(J-1))/(WAVE(J)-WAVE(J-1))
      XKSCT=SCATD(J-1)-(SCATD(J-1)-SCATD(J))*COMON
      XKABS=ABSOBD(J-1)-(ABSOBD(J-1)-ABSOBD(J))*COMON
CC    GBAR=ASYMD(J-1)-(ASYMD(J-1)-ASYMD(J))*COMON
      GO TO 100
   10 CONTINUE
  100 XKABS=XKABS*ASCAL
      XKSCT=XKSCT*ASCAL
      GO TO 105
   11 XKABS = 0.0
      XKSCT = 0.0
CC    GBAR  = 0.0
  105 XKABS = 1.0E-05 * XKABS
      XKSCT = 1.0E-05 * XKSCT
      RETURN
      END
```

```
      SUBROUTINE AGAGEO(HA1,GC1,GL1,AZ21,GA21,HA2,GC2,GL2)
CCC
C       SUBROUTINE AGAGEO (A MODIFIED HARC ROUTINE), GIVEN THE
C       GEOGRAPHIC COORDINATES OF POINT 1, THE AZIMUTH AND EARTH-CENTRAL
C       ANGLE OF POINT 2 WITH RESPECT TO POINT 1, AND THE HEIGHT OF
C       POINT 2, PROVIDES THE GEOGRAPHIC COORDINATES OF POINT 2.
CCC
C          INPUTS FROM CALL STATEMENT
C             HA1  = ALTITUDE OF POINT 1,  CM
C             GC1  = COLATITUDE OF POINT 1,  RADIANS
C             GL1  = EAST LONGITUDE OF POINT 1,  RADIANS
C             AZ21 = AZIMUTH ANGLE OF POINT 2 RELATIVE TO POINT 1,  RADS
C             GA21 = GEOCENTRIC ANGLE OF POINT 2 RELATIVE TO POINT 1, RAD
C             HA2  = ALTITUDE OF POINT 2,  CM
C          OUTPUTS
C             GC2  = COLATITUDE OF POINT 2,  RADIANS
C             GL2  = EAST LONGITUDE OF POINT 2,  RADIANS
CCC
      DATA  PI,RE / 3.141592653590,6.37103E+08 /
CCC
      IF( GA21.EQ.0.0 )  GO TO 100
      R1 = RE+HA1
      R2 = RE+HA2
      SR12 = SQRT(R1*R1 + R2*R2 - 2.*R1*R2*COS(GA21))
      IF( SR12.EQ.0.0 )  GO TO 100
      SINXI = R2*SIN(GA21)/SR12
      COSXI = (SR12**2 + R1**2 - R2**2)/(2.*SR12*R1)
      XI = ATAN2( SINXI,COSXI )
      HALFPI = PI/2.
      EL21 = XI-HALFPI
      CALL REATAN(SR12,EL21,AZ21,XE,YN,ZV)
      CALL TANGEO(HA1,GC1,GL1,XE,YN,ZV,HA22,GC2,GL2)
   99 RETURN
  100 GC2 = GC1
      GL2 = GL1
      GO TO 99
      END
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      SUBROUTINE ATMRAD ( LOGIC, ISHELL, XFRAC, DS, LBINT )            ATMRAD
C                                                                      ATMRAD
C        *ATMRAD* COMPUTES THE ATMOSPHERIC VOLUME EMISSION ON AN OPTICAL ATMRAD
C        PATH.                                                         ATMRAD
C                                                                      ATMRAD
CLJ   INPUT PARAMETERS                                                 ATMRAD
CLJ      ARGUMENT LIST                                                 ATMRAD
CLJ           LOGIC = LOGICAL VARIABLE                                 ATMRAD
CLJ                 = .TRUE.  ON FIRST ENTRY FROM SUBROUTINE TRNSCO    ATMRAD
CLJ                           (AND IS RESET TO .FALSE. IN ATMRAD).     ATMRAD
CLJ                 = .FALSE. ON SUBSEQUENT ENTRIES ALONG THE SAME PATH ATMRAD
CLJ       ISHELL(1) = INDX(I) IN CALL FROM TRNSCO                      ATMRAD
CLJ       ISHELL(2) = INDX(I+1) IN CALL FROM TRNSCO                    ATMRAD
CLJ       ISHELL(3) - USED IN EVALUATING THE LOGICAL VARIABLE TEST.    ATMRAD
CLJ                   WILL TYPICALLY BE EQUAL TO INDX(I+2), A POSITIVE ATMRAD
CLJ                   QUANTITY EXCEPT ON THE LAST CALL TO ATMRAD WHEN  ATMRAD
CLJ                   THE LAST PATH-SEGMENT IS BEING TREATED AT WHICH  ATMRAD
CLJ                   TIME ISHELL(3) WILL BECOME EQUAL TO INDX(NC+1)   ATMRAD
CLJ                   WHICH HAD BEEN SET TO 0 IN SUBROUTINE STEP.      ATMRAD
CLJ        XFRAC(1) = XFRACS(I) IN CALL FROM TRNSCO                    ATMRAD
CLJ        XFRAC(2) = XFRACS(I+1) IN CALL FROM TRNSCO                  ATMRAD
CLJ                   NOTE...  TO UNDERSTAND THE VALUES AND USES OF    ATMRAD
CLJ                   XFRACS(I), RECALL THAT THE TOTAL PATH HAS NC-1   ATMRAD
CLJ                   SEGMENTS AND NC ENDPOINTS OF THESE SEGMENTS.     ATMRAD
CLJ                   XFRACS(I) (I=1,NC) IS THE WEIGHT ASSOCIATED WITH ATMRAD
CLJ                   THE I-TH ENDPOINT APPROPRIATE FOR FINDING AT THAT ATMRAD
CLJ                   POINT THE LINEARLY-INTERPOLATED VALUE OF         ATMRAD
CLJ                   PARAMETERS -- SUCH AS TEMPERATURE AND PRESSURE   ATMRAD
CLJ                   (OR EVEN ALTITUDE) -- WHICH ARE SPECIFIED AT THE ATMRAD
CLJ                   TWO SHELL BOUNDARIES ADJACENT TO THE I-TH        ATMRAD
CLJ                   ENDPOINT.                                        ATMRAD
CLJ                   FOR VERIFICATION OF THIS INTERPRETATION, SEE THE ATMRAD
CLJ                   USAGE OF XFRAC(1) AND XFRAC(2) IN SUBROUTINE     ATMRAD
CLJ                   ATMRAD FOR OBTAINING ALTITUDE AND TEMPERATURE AT ATMRAD
CLJ                   FRONT AND BACK OF CELL DS.  THE SAME CONCLUSION  ATMRAD
CLJ                   MAY BE DRAWN FROM THE USAGE OF XFRACS(1) AND     ATMRAD
CLJ                   XFRACS(2) IN SUBROUTINE PATH.                    ATMRAD
CLJ                   CONSIDER A HYPOTHETICAL EXAMPLE WITH HSHELL(I)=0., ATMRAD
CLJ                   1.,2.,3. FOR I=1,2,3,4 AND 45-DEGREE PATH FROM   ATMRAD
CLJ                   ALTITUDE 1.9 TO 2.9 KM.  THEN NC=3 AND WE HAVE THE ATMRAD
CLJ                   FOLLOWING VALUES FOR THE ARRAYS.                 ATMRAD
CLJ                        I   DS(I)   XFRACS(I)  INDEX(I)             ATMRAD
CLJ                        -  -------  ---------  --------             ATMRAD
CLJ                        1  0.0        0.1        2                  ATMRAD
CLJ                        2  0.1414     1.0        3                  ATMRAD
CLJ                        3  1.2728     0.9        4                  ATMRAD
CLJ                        4  -1.0                  0                  ATMRAD
CLJ                                                                    ATMRAD
CLJ              DS = DS(I+1) IN CALL FROM TRNSCO                      ATMRAD
CLJ                   NOTE...  IT IS ALWAYS TRUE THAT DS(1)=0 AND      ATMRAD
CLJ                   DS(NC+1)=-1., WHERE NC IS THE NUMBER OF PATH     ATMRAD
CLJ                   SEGMENTS PLUS ONE.  ATMRAD WILL NOT BE CALLED    ATMRAD
CLJ                   WITH I=NC.    (CM)                               ATMRAD
CLJ           LBINT = WORD NO. 5 IN GRC'S DATASET-BN (NO. 114).        ATMRAD
CLJ                   STRICTLY, LBINT IS THE POINTER (I.E., CONTAINS THE ATMRAD
CLJ                   (Q-ARRAY) ADDRESS) FOR THE LIST HEADER OF THE    ATMRAD
CLJ                   BAND-INTERVAL DATASETS-BI CORRESPONDING TO       ATMRAD
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CLJ                  DATASET-BN.                                         ATMRAD
CLJ      XYZCOM COMMON                                                   ATMRAD
CLJ              FACT = PATH RESOLUTION FACTOR CONTROLLING THE NUMBER OF ATMRAD
CLJ                     ALTITUDES AND SPACING USED IN SUBROUTINE SHELLS. ATMRAD
CLJ                     SET IN DRIVER PROGRAM.  HERE IN SUBROUTINE ATMRAD, ATMRAD
CLJ                     FACT IS USED TO SET TOL, WHICH IS USED TO TEST   ATMRAD
CLJ                     TEMPERATURE DIFFERENCES ACROSS CELLS.            ATMRAD
CLJ         HSHELL(J) = ALTITUDE BOUNDARY, CM  (J=1,NS)  (HSHELL(1)=0.)  ATMRAD
CLJ             TS(J) = TEMPERATURE AT ALTITUDE BOUNDARY J, DEG K        ATMRAD
CLJ          U(I,N,2) = CUMULATIVE VALUE OF PATH PARAMETER U (AREAL      ATMRAD
CLJ                     DENSITY) FOR TEMPERATURE-INDEX I AND SPECIES N AT ATMRAD
CLJ                     END OF LINE SEGMENT DS,  CM AT STP               ATMRAD
CLJ         UP(I,N,2) = CUMULATIVE VALUE OF PATH PARAMETER UP (PRODUCT OF ATMRAD
CLJ                     U AND PRESSURE P) FOR TEMPERATURE-INDEX I AND    ATMRAD
CLJ                     SPECIES N AT END OF LINE SEGMENT DS,  ATM-CM     ATMRAD
CLJ                     AT STP        FOR U AND UP  (I=1,2 , N=1,10)     ATMRAD
CLJ             NMOLS = NUMBER OF SPECIES.  SET IN DRIVER.               ATMRAD
CLJ             LTMTE = BINARY FILE CONTAINING THE BAND-MODEL PARAMETERS ATMRAD
CLJ                     WHICH WERE DERIVED IN SUBROUTINE TRANSB FROM THE ATMRAD
CLJ                     BASIC 5-(1/CM)-RESOLUTION DATA.  HERE IN         ATMRAD
CLJ                     SUBROUTINE ATMRAD, FILE LTMTE IS REWOUND FOR USE ATMRAD
CLJ                     IN SUBROUTINE TRANS.                             ATMRAD
CLJ      OPTION COMMON                                                   ATMRAD
CLJ           TRNSOPT - LOGICAL VARIABLE AFFECTING COMPLEXITY OF MOLECULAR ATMRAD
CLJ                     TRANSMITTANCE CALCULATION (SEE SUBROUTINES TRANSB ATMRAD
CLJ                     AND TRANS).  IN SUBROUTINE ATMRAD, TRNSOPT IS USED ATMRAD
CLJ                     ONLY IN THE ARGUMENT LIST FOR THE CALL TO        ATMRAD
CLJ                     SUBROUTINE TRANS.                                ATMRAD
CLJ      DATASET BI  (BAND-INTERVAL DATASET, NO. 115)                    ATMRAD
CLJ              Q(1) = BNLO BI = LOW WAVELENGTH FOR WAVELENGTH-BAND-INDEX ATMRAD
CLJ                               J,  MICRONS                            ATMRAD
CLJ              Q(2) = BNHI BI = HIGH WAVELENGTH FOR WAVELENGTH-BAND-   ATMRAD
CLJ                               INDEX J,  MICRONS                      ATMRAD
CLJ              Q(3) = WLO  BI = LOW WAVENUMBER FOR WAVELENGTH-BAND-INDEX ATMRAD
CLJ                               J,  CM-1                               ATMRAD
CLJ              Q(4) = WHI  BI = HIGH WAVENUMBER FOR WAVELENGTH-BAND-   ATMRAD
CLJ                               INDEX J,  CM-1                         ATMRAD
CLJ   OUTPUT PARAMETERS                                                  ATMRAD
CLJ      DATASET BI                                                      ATMRAD
CLJ              Q(5) = BKGND BI = IN-BAND RADIANCE TO BACK OF CELL DS,  ATMRAD
CLJ                                WATTS/(CM**2 SR BAND)                 ATMRAD
CLJ              Q(7) = TRANS BI = PRODUCT OF MOLECULAR AND AEROSOL      ATMRAD
CLJ                                TRANSMITTANCE TO BACK OF CELL DS      ATMRAD
CLJ              Q(8) = IDSBX BI = CUMULATIVE AEROSOL TRANSMITTANCE TO   ATMRAD
CLJ                                BACK OF CELL DS                       ATMRAD
CLJ              *** NOTE ***  THIS IS THE SECOND OF TWO TEMPORARY USES OF ATMRAD
CLJ                       ***  WORD-8 (AND NOT THE GRC DICTIONARY USE OF ATMRAD
CLJ                       ***  WORD-8).  HERE, IT IS USED TO CARRY       ATMRAD
CLJ                       ***  INFORMATION TO SUBROUTINE UPWELL.         ATMRAD
CLJ                                                                      ATMRAD
CLJ   WE ALSO NOTE, FOR COMPLETENESS OF DATASET BI,                      ATMRAD
CLJ              Q(6) = TFLAG BI - SEE SUBROUTINE TRANSB FOR DEFINITION. ATMRAD
CLJ                                                                      ATMRAD
      COMMON QNAREA, QWAREA(10), QFREHD, QNDTST, QNLNKS, QZSIZE,         ATMRAD
     1       QNZBLK, QZHEAD, QCOUNT(30), QDSIZE(10), QNSIZE, QLUNIT(10), ATMRAD
     2       QERLUN, QFBITS(2,10), Q(1)                                  ATMRAD
      COMMON / XYZCOM / ITMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81),    ATMRAD
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      1              XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS,
      2              FACT
      COMMON / OPTION / TRNSOPT
      DIMENSION TAU(10), ABC(10), ISHELL(3), XFRAC(2)
      DIMENSION BNLO  BI(1), BNHI  BI(1), WLO   BI(1), WHI   BI(1),
     *          BKGND BI(1), TFLAG BI(1), TRANS BI(1), IDSBX BI(1)
      DIMENSION TDST  BX(1), DELTS BX(1), ABCLD BX(1), UVRB  BX(1),
     *          XKABS BX(1)
C
      EQUIVALENCE ( Q(1), BNLO  BI ), ( Q(2), BNHI  BI ),
     *            ( Q(3), WLO   BI ), ( Q(4), WHI   BI ),
     *            ( Q(5), BKGND BI ), ( Q(6), TFLAG BI ),
     *            ( Q(7), TRANS BI ), ( Q(8), IDSBX BI )
      EQUIVALENCE ( Q(1), TDST  BX ), ( Q(2), DELTS BX ),
     *            ( Q(3), ABCLD BX ), ( Q(4), UVRB  BX ),
     *            ( Q(5), XKABS BX )
CLJ
CLJ      DATASET-BX USED HERE IN SUBROUTINE ATMRAD IS A TEMPORARY
CLJ      FIVE-WORD DATASET WHICH SHOULD NOT BE CONFUSED WITH THE
CLJ      FIFTEEN-WORD DATASET-BX (NO. 118) USED IN THE GRC DICTIONARY
CLJ      OF DATASETS.
CLJ      DATASET-BX PROVIDES VARIOUS PROPERTIES AT THE FRONT OF THE
CLJ      CURRENT CELL DS.
CLJ         Q(1) = TDST BX = CUMULATIVE AEROSOL TRANSMITTANCE TO
CLJ                          FRONT OF CURRENT CELL
CLJ         Q(2) = DELTSBX = LENGTH OF LAST CELL (OR CELLS) IF IT (OR
CLJ                          THEY) WAS (OR WERE) SKIPPED OVER BECAUSE
CLJ                          TEST = .TRUE. ,  CM
CLJ         Q(3) = ABCLDBX = OPTICAL DEPTH AT FRONT OF CURRENT CELL,
CLJ                          DIMENSIONLESS
CLJ         Q(4) = UVRB BX = MOLECULAR ABSORPTION COEFFICIENT AT
CLJ                          FRONT OF CURRENT CELL DS,  1/CM
CLJ         Q(5) = XKABSBX = AEROSOL ABSORPTION COEFFICIENT,  1/CM
C
      LOGICAL TRNSOPT, LOGIC, TEST
C
      L1 = ISHELL(1)
      L2 = ISHELL(2)
CLJ      HSF,HSB  AND  TFRONT,TBACK  ARE, RESPECTIVELY, THE ALTITUDES
CLJ      AND TEMPERATURES AT THE FRONT AND BACK OF THE CURRENT CELL DS
CLJ      CORRESPONDING TO DS(I+1),  CM AND DEG K
      IF ( LOGIC ) HSF = XFRAC(1) * HSHELL(L1) + ( 1. - XFRAC(1) ) *
     $               HSHELL(L2)
      HSB = XFRAC(2) * HSHELL(L2) + ( 1. - XFRAC(2) ) * HSHELL(L1)
      IF ( LOGIC ) TFRONT = XFRAC(1) * TS(L1) + ( 1. - XFRAC(1) ) *
     $                  TS(L2)
      TBACK = XFRAC(2) * TS(L2) + ( 1. - XFRAC(2) ) * TS(L1)
CLJ      SET FILE POSITION FILPOS FOR USE IN SUBROUTINE TRANS.
      FILPOS = 1.E4
CLJ      TEST = .TRUE. PROVIDED THE TEMPERATURE CHANGE ACROSS A CELL IS
CLJ      LESS THAN ONE PERCENT (FOR THE STANDARD ATMOSPHERIC SHELL
CLJ      SPACING SET BY FACT=1) AND PROVIDED IT IS NEITHER THE FIRST
CLJ      NOR LAST CALL TO ATMRAD.
CLJ      *** NOTE ***   GRC (IN PROGRAM ATKGEN) SETS FACT TO 10.0 IF
CLJ                     TRNSOPT = .TRUE.
      TOL = 0.01 * SQRT( FACT )
      TEST = ABS( TFRONT - TBACK )/ TFRONT .LT. TOL   .AND.
```

```
     $       ISHELL(3) .GT. 0  .AND.  .NOT. LOGIC                        ATMRAD
CLJ       LOOP OVER SPECTRAL BAND-INTERVALS IN INCREASING WAVENUMBERS.   ATMRAD
      LINT = LBINT                                                       ATMRAD
    2 CALL PREV ( LINT, J )                                              ATMRAD
      IF ( J .EQ. 0 ) GO TO 10                                           ATMRAD
CLJ       CREATE A 5-WORD DATASET WITH INDEX JJ.  (IN OTHER WORDS, JJ IS ATMRAD
CLJ       THE ADDRESS OF THE FIRST OF THE FIVE WORDS.)                   ATMRAD
      IF ( LOGIC ) CALL CREATL ( 5, JJ )                                 ATMRAD
CLJ       CALL TO DSPWRD RETURNS ADDRESS, IDSBX BI(J)  (WHICH IS STORED  ATMRAD
CLJ       AS WORD-8 OF DATASET-BI), OF DSP WORD FOR THE DATASET-BX WHOSE ATMRAD
CLJ       FIRST-WORD ADDRESS IS JJ (ALL FOR EACH J).  (IN OTHER WORDS,   ATMRAD
CLJ       IDSBX BI(J) IS THE POINTER TO THE DSP WORD FOR THE DATASET-BX. ATMRAD
CLJ       ) THIS IS THE FIRST OF TWO TEMPORARY USES IN THIS ROUTINE OF   ATMRAD
CLJ       WORD-8 OF DATASET-BI.  HERE IT IS USED AS A POINTER TO THE DSP ATMRAD
CLJ       WORD FOR THE TEMPORARY DATASET-BX.                             ATMRAD
      IF ( LOGIC )  CALL DSPWRD ( JJ, IDSBX BI(J) )                      ATMRAD
      IF ( LOGIC )  TRANS BI(J) = 1.                                     ATMRAD
      IF ( LOGIC )  BKGND BI(J) = 0.                                     ATMRAD
      IF ( LOGIC ) TDST  BX(JJ) = 1.                                     ATMRAD
      IF ( LOGIC ) ABCLD BX(JJ) = 0.                                     ATMRAD
CLJ       CALL TO INDWRD RETURNS IN JJ THE INDEX (FIRST-WORD ADDRESS)    ATMRAD
CLJ       FOR THE DATASET-BX FOR WHICH THE POINTER TO ITS DSP WORD       ATMRAD
CLJ       (ZEROTH-WORD ADDRESS) IS STORED IN IDSBX BI(J) (WORD-8 OF      ATMRAD
CLJ       DATASET-BI).                                                   ATMRAD
      IF ( .NOT. LOGIC )  CALL INDWRD ( IDSBX BI(J), JJ )                ATMRAD
      WDL = WLO   BI(J)                                                  ATMRAD
      WDH = WHI   BI(J)                                                  ATMRAD
      W = .5 * ( WDL + WDH )                                             ATMRAD
CLJ       SET MEAN WAVENUMBER W FOR CALLING PLANCK AND MEAN WAVELENGTH   ATMRAD
CLJ       WAVEL FOR CALLING AEROSOL.                                     ATMRAD
      WAVEL = 1.E4/W                                                     ATMRAD
CLJ       DELTSBX(JJ) WILL NORMALLY EQUAL DS BECAUSE THE OLD DELTSBX(JJ) ATMRAD
CLJ       WAS INITIALLY ZEROED BY THE DSA SYSTEM AND SUBSEQUENTLY ZEROED ATMRAD
CLJ       AT THE END OF EACH PASS THROUGH ATMRAD, EXCEPT WHEN            ATMRAD
CLJ       TEST = .TRUE.                                                  ATMRAD
      DELTS BX(JJ) = DELTS BX(JJ) + DS                                   ATMRAD
      IF ( LOGIC )  CALL AEROSOL( HSF,WAVEL,XKSCA,XKABS BX(JJ),GBAR )    ATMRAD
      CALL AEROSOL( HSB,WAVEL,XKSCA,XKABS,GBAR )                         ATMRAD
CLJ       XKEXT IS THE AEROSOL EXTINCTION COEFFICIENT (1/CM) AT BACK OF  ATMRAD
CLJ       CURRENT CELL AND TDST IS THE AEROSOL TRANSMITTANCE TO THE BACK ATMRAD
CLJ       OF CURRENT CELL                                                ATMRAD
      XKEXT = XKSCA + XKABS                                              ATMRAD
      TDST = EXP( -XKEXT * DS ) * TDST  BX(JJ)                           ATMRAD
C         COMPUTE INCREMENTAL RADIANCE WHEN TEMPERATURE                  ATMRAD
C         CHANGE IS MORE THAN ONE PERCENT AT STANDARD PATH RESOLUTION    ATMRAD
      IF ( TEST ) GO TO 5                                                ATMRAD
CLJ       NOTE THAT SUBROUTINE TRANS RECEIVES THE ARRAYS U(I,N,2) AND    ATMRAD
CLJ       UP(I,N,2) AS U(I,N,1) AND UP(I,N,1).                           ATMRAD
      CALL TRANS ( 10, 1, U(1,1,2), UP(1,1,2), X1, WDL, WDH, TAU, ABC,   ATMRAD
     $            TNEW, TRNSOPT, FILPOS )                                ATMRAD
CLJ       NOW HAVE...                                                    ATMRAD
CLJ                ABC = OPTICAL-DEPTH ARRAY TO BACK OF CURRENT CELL FOR ATMRAD
CLJ                      SPECIES N=1,10                                  ATMRAD
CLJ               TNEW = MOLECULAR TRANSMITTANCE TO BACK OF CURRENT CELL ATMRAD
CLJ                TAU = MOLECULAR TRANSMITTANCE ARRAY TO BACK OF CURRENT ATMRAD
CLJ                      CELL FOR SPECIES N=1,10    (UNUSED HERE)        ATMRAD
CLJ       RESET TNEW TO BE THE PRODUCT OF THE MOLECULAR AND AEROSOL      ATMRAD
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```
CLJ      TRANSMITTANCE TO BACK OF CURRENT CELL  (DS)
      TNEW = TNEW * TDST
      ABCNEW = 0.
CLJ      COMPUTE OPTICAL DEPTH FOR ALL SPECIES, ABCNEW, TO BACK OF
CLJ      CELL DS.
      DO 3 N=1,NMOLS
    3 ABCNEW = ABCNEW + ABC(N)
      ABCNEW = AMAX1( ABCNEW, ABCLD BX(JJ) )
C        ACCUMULATE SPECTRAL RADIANCE AND TRANSMISSION ARRAYS
CLJ           UVRB = MOLECULAR ABSORPTION COEFFICIENT,  1/CM (NORMALLY
CLJ                  FOR CELL DS)
      UVRB = ( ABCNEW - ABCLD BX(JJ) ) / DELTS BX(JJ)
      IF ( LOGIC ) UVRB BX(JJ) = UVRB
      BBODYF = PLANCK( TFRONT, W )
      BBODYB = PLANCK( TBACK, W )
CLJ      COMPUTE IN-BAND RADIANCE TO BACK OF CELL DS BY AVERAGING OVER
CLJ      PATH SEGMENT DS WITH LOGARITHMIC INTERPOLATION.  THIS STEP IS
CLJ      VERY IMPORTANT.  THE FACTOR (WDH-WDL) CONVERTS FROM SPECTRAL
CLJ      TO IN-BAND RADIANCE.
      BKGND BI(J) = BKGND BI(J) + ACCUM( 2, O., DS, ( UVRB BX(JJ) +
     $             XKABS BX(JJ) )*BBODYF*TRANS BI(J), ( UVRB + XKABS )*
     $             BBODYB*TNEW, O., DS ) * ( WDH - WDL )
CLJ      SET VALUE OF MOLECULAR AND AEROSOL TRANSMITTANCE TO FRONT OF
CLJ      NEXT CELL FOR NEXT CALL TO ATMRAD.
      TRANS BI(J) = TNEW
CLJ      THE FOLLOWING TEST IS FOR THE LAST CELL.  THE CALL TO DSTROY
CLJ      REMOVES DATASET-BX AND ITS DSP WORD.  (THE INDEX JJ AND THE
CLJ      DSP WORD FOR DATASET-BX ARE SET TO ZERO.  THE SIX WORDS USED
CLJ      BY DATASET-BX ARE REGARDED AS FREE BY THE SYSTEM, THOUGH THEY
CLJ      HAVE NOT YET BEEN ZEROED.)  INVOKE SECOND TEMPORARY USE OF
CLJ      WORD-8 OF DATASET-BI BY SETTING IT EQUAL TO TDST.
       IF ( ISHELL(3) .EQ. 0 ) CALL DSTROY ( JJ )
       IF (ISHELL(3) .EQ. 0 )  CALL XMIT(1,TDST,IDSBX BI(J))
       IF (ISHELL(3) .EQ. 0 )  GO TO 2
CLJ      ZERO THE PATH-SEGMENT LENGTH, WHICH IS ALWAYS DONE UNLESS
CLJ      TEST = .TRUE.   ALSO, SET PROPERTIES AT FRONT OF NEXT CELL
CLJ      FOR NEXT CALL TO ATMRAD...
CLJ      ABCLD BX(JJ) =  OPTICAL DEPTH
CLJ      XKABS BX(JJ) =  AEROSOL ABSORPTION COEFFICIENT
CLJ      UVRB  BX(JJ) =  MOLECULAR ABSORPTION COEFFICIENT
CLJ      TDST  BX(JJ) =  AEROSOL TRANSMITTANCE
       DELTS BX(JJ) = 0.
       ABCLD BX(JJ) = ABCNEW
       XKABS BX(JJ) = XKABS
       UVRB  BX(JJ) = UVRB
    5  TDST  BX(JJ) = TDST
       GO TO 2
C
   10  IF ( TEST )  GO TO 11
       REWIND LTMTE
       HSF = HSB
       TFRONT = TBACK
   11  LOGIC = .FALSE.
       RETURN
       END
```

```
      FUNCTION CANGLE(P1LAT,P1LON,P2LAT,P2LON)                          CANGLE
CCC                                                                     CANGLE
C          FUNCTION CANGLE COMPUTES THE EARTH-CENTRAL ANGLE, CANGLE,    CANGLE
C          BETWEEN THE TWO CENTRAL RAYS TO POINTS P1 AND P2, GIVEN THE  CANGLE
C          LATITUDE AND LONGITUDES OF POINTS P1 AND P2.                 CANGLE
CCC                                                                     CANGLE
C          INPUT PARAMETERS                                             CANGLE
C          ARGUMENT LIST                                                CANGLE
C             P1LAT - NORTH LATITUDE OF POINT P1, RADIANS               CANGLE
C             P1LON - EAST LONGITUDE OF POINT P1, RADIANS               CANGLE
C             P2LAT - NORTH LATITUDE OF POINT P2, RADIANS               CANGLE
C             P2LON - EAST LONGITUDE OF POINT P2, RADIANS               CANGLE
C          OUTPUT PARAMETER                                             CANGLE
C             CANGLE - EARTH-CENTRAL ANGLE BETWEEN RAYS TO POINTS       CANGLE
C                      P1 AND P2                                        CANGLE
CCC                                                                     CANGLE
C          CONSIDER THE SPHERICAL TRIANGLE P1-N-P2, WHERE N IS AT       CANGLE
C          THE NORTH POLE.                                              CANGLE
CCC                                                                     CANGLE
      SINSIN = SIN(P1LAT)*SIN(P2LAT)                                    CANGLE
      COSCOS = COS(P1LAT)*COS(P2LAT)                                    CANGLE
      ALPHAC = ACOS( SINSIN + COSCOS*COS(P2LON-P1LON) )                 CANGLE
      CANGLE = ALPHAC                                                   CANGLE
      RETURN                                                            CANGLE
      END                                                               CANGLE
```

```
      FUNCTION DOT ( X, Y )                                             DOT
C                                                                       DOT
C         *DOT* FORMS THE DOT PRODUCT OF TWO VECTORS.                   DOT
C                                                                       DOT
      DIMENSION X(3), Y(3)                                              DOT
      DOT = X(1) * Y(1) + X(2) * Y(2) + X(3) * Y(3)                     DOT
      RETURN                                                            DOT
      END                                                               DOT
```

```
      FUNCTION ERF(X)                                                   ERFF
C          ERF IS THE ERROR FUNCTION, BASED ON THE RATIONAL-APPROXIMATION ERFF
C          FORMULA 7.1.2.6 IN THE NBS APPLIED MATH. SERIES NO. 55 (BUT  ERFF
C          WITH CONSTANTS REDUCED TO SEVEN DIGITS).                     ERFF
C                                                                       ERFF
      Y = 1.0                                                           ERFF
      IF(ABS(X)-4.0) 1,1,2                                              ERFF
    1 T = 1.0/(1.+0.3275911*ABS(X))                                     ERFF
      Y = 1. - ((((1.061405*T - 1.453152)*T + 1.421414)*T - 0.2844967)*T ERFF
     1 + 0.2548296)*T*EXP(-X*X)                                         ERFF
    2 ERF = SIGN(Y,X)                                                   ERFF
      RETURN                                                            ERFF
      END                                                               ERFF
```

```
      SUBROUTINE ESURF(THI,THR,PSI,ZKM,MSM,DD,SPCULR,ZLAM,IDAY,IFIRES,
     * ESURF1,SFR,EPSD,TKS)
CCC
C        SUBROUTINE ESURF PROVIDES THE BIDIRECTIONAL REFLECTANCE
C        DISTRIBUTION FUNCTION (BRDF), DIRECTIONAL EMISSIVITY, AND
C        TEMPERATURE OF THE EARTH'S SURFACE AT THE INTERSECTION POINT
C        OF THE OPTICAL LINE-OF-SIGHT. SINCE THE SURFACE CATEGORY IS
C        NOT AUTOMATICALLY CORRELATED WITH THE GEOGRAPHIC POSITION,
C        THE USER MUST SELECT ONE OF THE SEVEN CATEGORIES PROVIDED.
CCC
C        INPUT PARAMETERS
C            ARGUMENT LIST
C              THI = ZENITH ANGLE OF SOURCE (E.G., SUN OR FIREBALL) AT
C                    INTERSECTION POINT,  RADIANS
C                    WHEN SUBROUTINE SURRAD IS CALLED FROM SUBROUTINE
C                    UPWELL, AS IT IS IN THE NBR MODULE, THI IS SET IN
C                    SURRAD TO AN ARBITRARY (NON-PHYSICAL) VALUE OF
C                    -1.0 FOR NIGHTTIME CONDITIONS.
C              THR = ZENITH ANGLE OF LINE-OF-SIGHT AT INTERSECTION
C                    POINT,  RADIANS
C              PSI = AZIMUTH ANGLE (AT INTERSECTION POINT) OF VERTICAL
C                    PLANE THROUGH LINE-OF-SIGHT, MEASURED RELATIVE TO
C                    THE SOURCE PRINCIPAL PLANE (I.E., VERTICAL PLANE
C                    THROUGH SOURCE RAY). A VALUE OF PSI=0 CORRESPONDS
C                    TO FORWARD SCATTERING.  IN RADIANS
C                    FOR NIGHTTIME CONDITIONS, PSI IS SET TO -1.0.  SEE
C                    COMMENT ABOVE FOR THI.
C              ZKM = ALTITUDE OF SURFACE,  KM
C              MSM = INDEX FOR CATEGORY OF SURFACE MATERIAL.
C                  = 1, LAMBERTIAN DIFFUSE SURFACE WITH SPECTRALLY-
C                       INDEPENDENT REFLECTANCE SET BY DD(1) AND
C                       EMISSIVITY BY (1.-DD(1)).
C                  = 2, WATER
C                  = 3, SNOW
C                  = 4, SAND
C                  = 5, SOIL
C                  = 6, FOLIAGE
C                  = 7, URBAN MATERIAL
C            DD(M) = ADDITIONAL DESCRIPTOR FOR SELECTED SURFACE
C                    MATERIAL.
C            FOR M = 1, (LAMBERTIAN SURFACE), DD(1) = DIFFUSE
C                       REFLECTANCE. TYPICAL VALUE IS 0.10
C            FOR M = 2, (WATER), DD(2) = WIND SPEED, M/SEC.
C            FOR M = 3, (SNOW), DD(3) = SNOW-AGE PARAMETER,
C                       DD(3).GE.O. .AND. .LE.1.   VALUES OF 0. AND 1.
C                       CORRESPOND TO NEW AND OLD SNOW RESPECTIVELY.
C            FOR M = 4,5,6,  DD(M) NOT USED.
C            FOR M = 7, (URBAN MATERIAL), DD(7)=DEGREE-OF-URBANIZATION,
C                       DD(7).GE.O. .AND. .LE.1.   FOR DD(7) = 0., THE
C                       SPECTRAL BRDF CORRESPONDS TO A FLAT SURFACE
C                       WITH AVERAGE DIRECTIONAL-REFLECTANCE PROPERTIES
C                       OF CONCRETE AND ASPHALT. FOR DD(7) = 1., THE
C                       SPECTRAL BRDF CORRESPONDS TO A DIFFUSE
C                       REFLECTOR MULTIPLIED BY A SHADOW-FACTOR
C                       S(THI,THR) = ( COS(THI) + COS(THR) )/2.
C           SPCULR = LOGICAL PARAMETER
C                  = .TRUE.  COMPUTE COORDINATES OF SPECULAR
```

```
C                          REFLECTION POINT                         ESURF
C                 = .FALSE. DO NOT COMPUTE COORDINATES OF SPECULAR  ESURF
C                          REFLECTION POINT                         ESURF
C           ZLAM = WAVELENGTH,  MICROMETERS                         ESURF
C           IDAY = INDEX FOR DAYLIGHT CONDITIONS AT POINT P         ESURF
C                = 0  IF SOLAR ZENITH ANGLE .GT. 90 DEGREES         ESURF
C                = 1  IF SOLAR ZENITH ANGLE .LE. 90 DEGREES         ESURF
C         IFIRES = FLAG FOR INCLUSION OF FIREBALLS                  ESURF
C                = 0  IF NO FIREBALL IS BEING CONSIDERED            ESURF
C                     WHICH IS ALWAYS THE CASE IN THE NBR MODULE.   ESURF
C                .GT. 0  IF FIREBALLS ARE BEING CONSIDERED          ESURF
C         ESURF1 = LOGICAL PARAMETER                                ESURF
C                = .TRUE.  IF ESURF IS CALLED FOR THE FIRST TIME FROM ESURF
C                          SUBROUTINE SURRAD AND BOTH EPSD AND TKS  ESURF
C                          ARE WANTED IN ADDITION TO SFR AS OUTPUTS, ESURF
C                          WHICH IS ALWAYS THE CASE IN THE NBR MODULE ESURF
C                = .FALSE. IF ESURF IS NOT BEING CALLED FOR THE FIRST ESURF
C                          TIME FROM SUBROUTINE SURRAD AND A RECOMPU- ESURF
C                          TATION OF EPSD AND TKS IS NOT NEEDED, A  ESURF
C                          POSSIBILITY WHICH OCCURS ONLY IF         ESURF
C                          SUBROUTINE SURRAD IS USED AS A UTILITY   ESURF
C                          ROUTINE WITH FIREBALLS AS SOURCES.       ESURF
CCC                                                                 ESURF
C       ATMOUP COMMON                                               ESURF
C             TT = AMBIENT ATMOSPHERIC TEMPERATURE AT ALTITUDE ZKM.  ESURF
CCC                                                                 ESURF
C       OUTPUT PARAMETERS                                           ESURF
C           ARGUMENT LIST                                           ESURF
C             SFR = FSUBR(M,DD(M),ZLAM'THI,THR,PSI)                 ESURF
C                 = BIDIRECTIONAL REFLECTANCE DISTRIBUTION          ESURF
C                   FUNCTION,  1./SR                                ESURF
C                   (COMPUTED ONLY IF SOURCE IS ABOVE THE HORIZON)  ESURF
C            EPSD = 1.0 - RHOSUBM(ZLAM'THR,2*PI)                    ESURF
C                 = DIRECTIONAL EMISSIVITY, DIMENSIONLESS.          ESURF
C             TKS = SURFACE TEMPERATURE, DEG K.                     ESURF
C           POSITN COMMON                                           ESURF
C              THIS OUTPUT OBTAINS ONLY IF MSM=2 AND SPCULR=.TRUE.  ESURF
C              SPCLAT - NORTH LATITUDE OF POINT ON SMOOTH HORIZONTAL ESURF
C                       WATER SURFACE FOR A SPECULAR REFLECTION FROM ESURF
C                       THE SOURCE TO THE DETECTOR (COMPUTED IN     ESURF
C                       SUBROUTINE GLITTR),  RADIANS                ESURF
C              SPCLON - EAST LONGITUDE OF POINT ON SMOOTH HORIZONTAL ESURF
C                       WATER SURFACE FOR A SPECULAR REFLECTION FROM ESURF
C                       THE SOURCE TO THE DETECTOR (COMPUTED IN     ESURF
C                       SUBROUTINE GLITTR),  RADIANS                ESURF
CCC                                                                 ESURF
      DIMENSION  DD(7),ALPM(7),BETM(7),GAMM(7),RMOO(7),RMPI(7),LL(7) ESURF
      DIMENSION  WV4(18),WV5(16),WV6(12),WV7(23),GTHIO(7)           ESURF
      DIMENSION  SP4(18),SP5(16),SP6(12),SP7(23)                    ESURF
      COMMON/ATMOUP/ H ,SBAR,IDORN,PP,RHO,TT,SNI(30),HRHO,FEHSEQ    ATMOUP
      COMMON/POSITN/  POSLAT,POSLON,POSALT,SPCLAT,SPCLON            POSITN
     $               ,C12LAT,C12LON,C12ALT                          POSITN
      LOGICAL  SPCULR,ESURF1                                        ESURF
      DATA  (ALPM(I),I=1, 7) / 0.,0.,3.,3.,2.5,2.5,4. /             ESURF
      DATA  (BETM(I),I=1, 7) / 0.,0.,0.9,0.5,0.5,0.5,0.5 /          ESURF
      DATA  (GAMM(I),I=1, 7) / 0.,0.,1.,1.,2.,2.,2. /               ESURF
      DATA  (RMOO(I),I=1, 7) / 0.,0.,13.,2.5,1.,1.,10.5 /           ESURF
```

```
      DATA  (RMPI(I),I=1, 7) / 0.,0.,3.,4.,4.,10.,1. /                   ESURF
      DATA  (GTHIO(I),I=1,7) / 1.,0.,1.024,1.015,1.043,1.095,1.011 /     ESURF
      DATA  (LL(I),    I=1,7) / 0,0,0,18,16,12,23 /                      ESURF
      DATA  PI / 3.141592653590 /                                        ESURF
C          SPECTRAL PARAMETERS FOR SAND.                                 ESURF
      DATA  (WV4(I),I=1,18) / 2.00,2.05,2.18,2.30,2.45,2.50,2.63,2.73,   ESURF
     *                        2.88,2.95,3.20,3.30,3.60,3.75,3.90,4.35,   ESURF
     *    4.90,5.00 /                                                    ESURF
      DATA  (SP4(I),I=1,18) / 0.205,0.238,0.209,0.206,0.177,0.174,0.148, ESURF
     *                        0.114,0.080,0.040,0.070,0.093,0.145,0.162, ESURF
     *      0.152,0.076,0.031,0.035 /                                    ESURF
C          SPECTRAL PARAMETERS FOR SOIL.                                 ESURF
      DATA  (WV5(I),I=1,16) / 2.00,2.08,2.25,2.50,2.62,2.70,2.77,2.92,   ESURF
     *                        3.15,3.50,3.70,3.82,4.10,4.60,4.77,5.00 /  ESURF
      DATA  (SP5(I),I=1,16) / 0.262,0.272,0.257,0.227,0.198,0.095,0.067, ESURF
     *                        0.061,0.067,0.112,0.158,0.177,0.195,0.158, ESURF
     *      0.142,0.113 /                                                ESURF
C          SPECTRAL PARAMETERS FOR VEGETATION.                           ESURF
      DATA  (WV6(I),I=1,12) / 2.00,2.20,2.64,2.78,2.96,3.03,3.16,3.22,   ESURF
     *                        3.42,3.58,3.95,5.00 /                      ESURF
      DATA  (SP6(I),I=1,12) / 0.129,0.212,0.059,0.059,0.120,0.120,0.033, ESURF
     *                        0.033,0.074,0.074,0.037,0.021 /            ESURF
C          SPECTRAL PARAMETERS FOR URBAN MATERIALS.                      ESURF
      DATA  (WV7(I),I=1,23) / 2.00,2.12,2.24,2.26,2.36,2.47,2.55,2.63,   ESURF
     *                        2.70,2.85,2.89,3.00,3.10,3.24,3.62,3.89,   ESURF
     *    4.00,4.10,4.26,4.42,4.70,4.83,5.00 /                           ESURF
      DATA  (SP7(I),I=1,23) / 0.347,0.348,0.326,0.278,0.272,0.295,0.299, ESURF
     *                        0.296,0.272,0.145,0.118,0.090,0.091,0.100, ESURF
     *      0.149,0.193,0.231,0.238,0.240,0.254,0.246,0.229,0.215 /      ESURF
CCC                                                                      ESURF
CC         CHECK MATERIAL INDEX FOR PROPER RANGE                         ESURF
      IF( (MSM.LT.1) .OR. (MSM.GT.7) )  GO TO 101                        ESURF
      IF( .NOT.ESURF1 )  GO TO 50                                        ESURF
CC         GET SURFACE TEMPERATURE TAKEN TO BE AIR TEMPERATURE           ESURF
CC         AT ALTITUDE ZKM.                                              ESURF
      CALL ATMOSU(2,ZKM)                                                 ESURF
      TKS = TT                                                           ESURF
   50 IF( MSM.GT.1 )  GO TO 99                                           ESURF
CC         SET PROPERTIES FOR MSM=1  (THE VALUE -1.0 FOR SFR IS AN       ESURF
CC         ARBITRARY DEFAULT SETTING WHICH WILL NEVER BE USED)           ESURF
      SFR = -1.0                                                         ESURF
      IF( (IDAY.EQ.1) .OR. (IFIRES.GT.0) )  SFR = DD(1)/PI               ESURF
      EPSD = 1.0-DD(1)                                                   ESURF
      RETURN                                                             ESURF
   99 IF( MSM.GT.2 )  GO TO 100                                          ESURF
      CALL GLITTR(THI,DD(2),SPCULR,ZLAM,IDAY,IFIRES,ESURF1,SFR,EPSD)     ESURF
      RETURN                                                             ESURF
  100 ALPHA = ALPM(MSM)                                                  ESURF
      BETA = BETM(MSM)                                                   ESURF
      GAMMA = GAMM(MSM)                                                  ESURF
      RMZ = RMOO(MSM)                                                    ESURF
      RMP = RMPI(MSM)                                                    ESURF
      LLM = LL(MSM)                                                      ESURF
      GTHIOA = GTHIO(MSM)                                                ESURF
CC         OBTAIN THE SPECTRAL, NORMAL-INCIDENCE--HEMISPHERICAL          ESURF
CC         REFLECTANCE, RHOM(ZLAM), BASED ON TABLE 2-3 IN TEXT.          ESURF
      GO TO (101,101,103,104,105,106,107),  MSM                          ESURF
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  101 WRITE(6,13)  MSM                                                   ESURF
   13 FORMAT (44H0  ERROR IN VALUE OF MSM-(SEE ESURF),   MSM=,I5)        ESURF
      CALL EXIT                                                          ESURF
CC              FOR SNOW (MSM=3)                                         ESURF
  103 RHOM  = (0.44-0.12*(ZLAM-2.))*(1.0-DD(3)*5./12.)                   ESURF
      GO TO 110                                                          ESURF
CC              FOR SAND (MSM=4)                                         ESURF
  104 CALL LINEAR (ZLAM,RHOM,WV4,SP4,LLM)                                ESURF
      GO TO 110                                                          ESURF
CC              FOR SOIL (MSM=5)                                         ESURF
  105 CALL LINEAR (ZLAM,RHOM,WV5,SP5,LLM)                                ESURF
      GO TO 110                                                          ESURF
CC              FOR FOLIAGE (MSM=6)                                      ESURF
  106 CALL LINEAR (ZLAM,RHOM,WV6,SP6,LLM)                                ESURF
      GO TO 110                                                          ESURF
CC              FOR URBAN MATERIAL (MSM=7)                               ESURF
  107 CALL LINEAR (ZLAM,RHOM,WV7,SP7,LLM)                                ESURF
CC        COMPUTE APPROXIMATE VALUE FOR THE SPECTRAL PARAMETER           ESURF
CC        RHOZM(ZLAM) BY USING EQ.(6'') IN TEXT.                         ESURF
  110 RHOZM = RHOM/(PI*GTHIOA)                                           ESURF
CC        PROTECT AGAINST ABORT FOR GRAZING RAYS.                        ESURF
      CTHI = COS( THI )                                                  ESURF
      CTHR = COS( THR )                                                  ESURF
CC        IF THI OR THR GREATER THAN 89.9 DEGREES RESET TO 89.9 .        ESURF
      IF( ABS(CTHI).LT.1.745E-03 )  CTHI = 1.745E-03                     ESURF
      IF( ABS(CTHR).LT.1.745E-03 )  CTHR = 1.745E-03                     ESURF
CC        EVALUATE AUXILIARY PARAMETERS NEEDED REGARDLESS OF PRESENCE    ESURF
CC        OF SOURCE.                                                     ESURF
      RBAR = 0.5*(RMZ+RMP)                                               ESURF
      SA = ALPHA*BETA                                                    ESURF
      P1A = (1.0-EXP(-SA))/SA                                            ESURF
CC        NEED NOT COMPUTE SFR IF NEITHER SUN NOR FIREBALL IS            ESURF
CC        CONSIDERED AS A SOURCE, SO SET IT (ARBITRARILY) TO -1.0        ESURF
      SFR = -1.0                                                         ESURF
      IF( (IDAY.EQ.0) .AND. (IFIRES.EQ.0) )  GO TO 124                   ESURF
      IF( (THI.GT.0.0) .OR. (THR.GT.0.0) )  GO TO 120                    ESURF
CC        EVALUATE SFR AVERAGED OVER AZIMUTH ANGLES, FROM EQ.(3A) IN     ESURF
CC        TEXT.                                                          ESURF
      SFR = RHOZM*(1.0+RBAR*P1A*EXP(-2.*ALPHA))                          ESURF
      CTHR = 1.0                                                         ESURF
      GO TO 122                                                          ESURF
  120 ABTF = BETA*(1.0-ABS(1.0-2.*PSI/PI))                               ESURF
      CGAM = CTHI**GAMMA + CTHR**GAMMA                                   ESURF
      RMPSI = RMZ - (RMZ-RMP)*PSI/PI                                     ESURF
CC        EVALUATE EQ.(1) IN TEXT.                                       ESURF
      SFR = RHOZM*(1.0+RMPSI*EXP(-ALPHA*(CGAM+ABTF)))                    ESURF
  122 IF( MSM.NE.7 )  GO TO 124                                          ESURF
CC        FOR MSM=7, EVALUATE EQ.(17) IN TEXT FOR SFR.                   ESURF
      URBAN = RHOZM*DD(7)*(CTHI+CTHR)/2.                                 ESURF
      SFR = URBAN + SFR*(1.0-DD(7))                                      ESURF
  124 IF( .NOT.ESURF1 )  RETURN                                          ESURF
CC        PREPARE TO COMPUTE DIRECTIONAL EMISSIVITY.                     ESURF
CC        EVALUATE EQ.(10) IN TEXT WITH THETA REPLACED BY THR.           ESURF
      FGAMM = EXP(-ALPHA*CTHR**GAMMA)                                    ESURF
      IGAM = GAMMA+0.25                                                  ESURF
      GO TO (126,128), IGAM                                              ESURF
CC        EVALUATE EQ.(8) IN TEXT.                                       ESURF
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  126 P2GAM = (1.0-(ALPHA+1.)*EXP(-ALPHA))/(ALPHA*ALPHA)              ESURF
      GO TO 130                                                      ESURF
CC        EVALUATE EQ.(9) IN TEXT.                                   ESURF
  128 P2GAM = (1.0-EXP(-ALPHA))/(2.*ALPHA)                           ESURF
CC        FRHOM = DIRECTIONAL-HEMISPHERICAL REFLECTANCE              ESURF
CC        EPSD = DIRECTIONAL EMISSIVITY                              ESURF
CC        EVALUATE EQ.(6) IN TEXT, BUT WITH THI REPLACED BY THR IN THE ESURF
CC        ANTICIPATION THAT FRHOM WILL BE USED IN EQ.(12) FOR THE    ESURF
CC        DIRECTIONAL EMISSIVITY.                                    ESURF
  130 FRHOM = PI*RHOZM  *  (1.0+2.*P1A*P2GAM*RBAR*FGAMM)             ESURF
      IF( MSM.NE.7 )  GO TO 140                                      ESURF
CC        FOR MSM=7, EVALUATE EQ.(18) IN TEXT, BUT WITH THI REPLACED BY  ESURF
CC        THR IN THE ANTICIPATION THAT FRHOM WILL BE USED IN EQ.(19) FOR ESURF
CC        THE DIRECTIONAL EMISSIVITY.                                ESURF
      FRHOM = (1.-DD(7))*FRHOM + DD(7)*RHOZM*PI*(0.50*CTHR + 0.333333)  ESURF
CC        EVALUATE EQ.(12) IN TEXT.                                  ESURF
  140 EPSD = 1.0-FRHOM                                               ESURF
      RETURN                                                         ESURF
      END                                                            ESURF
```

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      FUNCTION FRAC ( A, B, X, Y )                                   FRAC
C                                                                    FRAC
C         *FRAC* CALCULATES THE FRACTION OF INTERVAL (A,B)           FRAC
CLJ       CONTAINED IN INTERVAL (X,Y) IF( (A,B) .LE. (X,Y) )  OR     FRAC
CLJ       COVERED   BY INTERVAL (X,Y) IF( (A,B) .GT. (X,Y) ).        FRAC
C                                                                    FRAC
      D = A - B                                                      FRAC
      FR1 = AMAX1( AMIN1( (A - Y)/D, 1. ), 0. )                      FRAC
      FR2 = AMAX1( AMIN1( (X - B)/D, 1. ), 0. )                      FRAC
      FRAC = FR1 + FR2 - 1.                                          FRAC
      RETURN                                                         FRAC
      END                                                            FRAC
```

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      SUBROUTINE FRESNL(ZLAM,OMEGA,RHO)                                 FRESNL
CCC                                                                     FRESNL
C        SUBROUTINE FRESNL EVALUATES THE FRESNEL (SPECULAR)             FRESNL
C        MONOCHROMATIC REFLECTANCE OF A SMOOTH WATER SURFACE, GIVEN     FRESNL
C        THE WAVELENGTH AND ANGLE OF INCIDENCE.                         FRESNL
CCC                                                                     FRESNL
C        INPUT PARAMETERS                                               FRESNL
C            ARGUMENT LIST                                              FRESNL
C            ZLAM - WAVELENGTH (MICROMETERS)                            FRESNL
C           OMEGA - ANGLE OF INCIDENCE (WITH RESPECT TO NORMAL TO       FRESNL
C                   SMOOTH ELEMENT OF WATER SURFACE)  (RADIANS)         FRESNL
CCC                                                                     FRESNL
C        OUTPUT PARAMETER                                               FRESNL
C            ARGUMENT LIST                                              FRESNL
C             RHO - FRESNEL MONOCHROMATIC REFLECTANCE OF PLANE,         FRESNL
C                   UNPOLARIZED ELECTROMAGNETIC WAVE INCIDENT AT        FRESNL
C                   ANGLE OMEGA ON PLANE, ABSORBING SURFACE WITH        FRESNL
C                   COMPLEX INDEX OF REFRACTION  NN = SN - I*SK         FRESNL
CCC                                                                     FRESNL
      DIMENSION  SNNU(222), SKNU(222)                                   FRESNL
C                                                                       FRESNL
C        THE VALUES OF THE COMPLEX INDEX OF REFRACTION ARE TAKEN FROM   FRESNL
C        H. D. DOWNING AND D. WILLIAMS, OPTICAL CONSTANTS OF WATER IN   FRESNL
C        THE INFRARED, J. GEOPHYS. RES. VOL. 80, 1656(1975).            FRESNL
C                                                                       FRESNL
      DATA  (SNNU(I),I=1,142) / 1.321,1.322,1.322,1.323,1.324,1.324,    FRESNL
     *                          1.325,1.325,1.325,1.325,1.325,1.325,    FRESNL
     *  1.326,1.326,1.326,1.327,1.327,1.327,1.327,1.327,1.328,1.328,    FRESNL
     *  1.329,1.329,1.329,1.330,1.330,1.330,1.331,1.332,1.332,1.333,    FRESNL
     *  1.334,1.334,1.335,1.337,1.337,1.338,1.340,1.340,1.341,1.342,    FRESNL
     *  1.343,1.344,1.344,1.345,1.346,1.347,1.348,1.348,1.349,1.350,    FRESNL
     *  1.351,1.352,1.353.1.354,1.355,1.357,1.358,1.358,1.360,1.361,    FRESNL
     *  1.361,1.363,1.365,1.366,1.367,1.369,1.370,1.371,1.372,1.374,    FRESNL
     *  1.375,1.377,1.378,1.379,1.382,1.383,1.385,1.387,1.388,1.390,    FRESNL
     *  1.392,1.394,1.396,1.398,1.400,1.403,1.405,1.407,1.410,1.413,    FRESNL
     *  1.415,1.418,1.421,1.425,1.427,1.431,1.434,1.437,1.441,1.444,    FRESNL
     *  1.448,1.451,1.454,1.457,1.461,1.464,1.467,1.472,1.474,1.477,    FRESNL
     *  1.479,1.482,1.485,1.486,1.487,1.487,1.487,1.486,1.483,1.480,    FRESNL
     *  1.476,1.471,1.465,1.457,1.450,1.442,1.434,1.426,1.417,1.407,    FRESNL
     *  1.398,1.386,1.376,1.364,1.353,1.342,1.329,1.317,1.305,1.293 /   FRESNL
      DATA  (SNNU(I),I=143,222) /     1.282,1.271,1.258,1.246,1.233,    FRESNL
     *                                1.220,1.212,1.199,1.191,1.183,    FRESNL
     *  1.177,1.171,1.165,1.161,1.158,1.154,1.149,1.144,1.141,1.139,    FRESNL
     *  1.138,1.138,1.139,1.144,1.149,1.157,1.166,1.172,1.179,1.185,    FRESNL
     *  1.191,1.195,1.200,1.205,1.210,1.214,1.218,1.221,1.224,1.227,    FRESNL
     *  1.230,1.232,1.235,1.238,1.240,1.241,1.243,1.246,1.247,1.249,    FRESNL
     *  1.250,1.252,1.254,1.255,1.256,1.257,1.259,1.260,1.261,1.265,    FRESNL
     *  1.270,1.274,1.277,1.280,1.282,1.285,1.287,1.289,1.291,1.293,    FRESNL
     *  1.294,1.295,1.296,1.298,1.298,1.300,1.301,1.301,1.303,0.0 /     FRESNL
      DATA  (SKNU(I),I=1,112) /       1.26E-2,1.29E-2,1.33E-2,1.37E-2,  FRESNL
     *                                1.40E-2,1.43E-2,1.46E-2,1.48E-2,  FRESNL
     * 1.51E-2,1.53E-2,1.55E-2,1.57E-2,1.57E-2,1.57E-2,1.56E-2,1.54E-2,  FRESNL
     * 1.52E-2,1.49E-2,1.45E-2,1.40E-2,1.36E-2,1.31E-2,1.26E-2,1.22E-2,  FRESNL
     * 1.17E-2,1.12E-2,1.08E-2,1.04E-2,1.00E-2,9.66E-3,9.27E-3,8.96E-3,  FRESNL
     * 8.64E-3,8.33E-3,8.06E-3,7.79E-3,7.49E-3,7.22E-3,6.96E-3,6.73E-3,  FRESNL
     * 6.53E-3,6.31E-3,6.08E-3,5.86E-3,5.68E-3,5.49E-3,5.31E-3,5.12E-3,  FRESNL
     * 4.94E-3,4.79E-3,4.65E-3,4.50E-3,4.33E-3,4.22E-3,4.10E-3,3.99E-3,  FRESNL
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     * 3.89E-3,3.78E-3,3.70E-3,3.63E-3,3.52E-3,3.48E-3,3.40E-3,3.39E-3,  FRESNL
     * 3.35E-3,3.36E-3,3.35E-3,3.40E-3,3.47E-3,3.55E-3,3.63E-3,3.76E-3,  FRESNL
     * 3.89E-3,4.05E-3,4.24E-3,4.49E-3,4.73E-3,5.06E-3,5.38E-3,5.79E-3,  FRESNL
     * 6.25E-3,6.83E-3,7.37E-3,8.07E-3,8.66E-3,9.41E-3,1.01E-2,1.10E-2,  FRESNL
     * 1.18E-2,1.28E-2,1.38E-2,1.51E-2,1.63E-2,1.77E-2,1.93E-2,2.10E-2,  FRESNL
     * 2.29E-2,2.50E-2,2.62E-2,2.79E-2,2.97E-2,3.15E-2,3.48E-2,3.85E-2,  FRESNL
     * 4.22E-2,4.62E-2,5.04E-2,5.50E-2,6.00E-2,6.53E-2,7.16E-2,7.85E-2 / FRESNL
      DATA  (SKNU(I),I=113,222) /      8.55E-2,9.20E-2,9.94E-2,1.10E-1,  FRESNL
     *                                 1.17E-1,1.25E-1,1.34E-1,1.44E-1,  FRESNL
     * 1.53E-1,1.63E-1,1.73E-1,1.83E-1,1.95E-1,2.04E-1,2.12E-1,2.20E-1,  FRESNL
     * 2.28E-1,2.36E-1,2.43E-1,2.50E-1,2.55E-1,2.62E-1,2.67E-1,2.72E-1,  FRESNL
     * 2.76E-1,2.79E-1,2.82E-1,2.82E-1,2.81E-1,2.80E-1,2.76E-1,2.71E-1,  FRESNL
     * 2.65E-1,2.58E-1,2.49E-1,2.39E-1,2.29E-1,2.18E-1,2.06E-1,1.94E-1,  FRESNL
     * 1.80E-1,1.67E-1,1.54E-1,1.42E-1,1.31E-1,1.21E-1,1.12E-1,1.02E-1,  FRESNL
     * 9.27E-2,8.36E-2,7.44E-2,6.49E-2,5.48E-2,4.62E-2,3.80E-2,2.82E-2,  FRESNL
     * 2.05E-2,1.86E-2,1.64E-2,1.45E-2,1.27E-2,1.05E-2,8.55E-3,7.32E-3,  FRESNL
     * 6.27E-3,5.36E-3,4.82E-3,4.37E-3,4.02E-3,3.30E-3,2.98E-3,2.70E-3,  FRESNL
     * 2.57E-3,2.48E-3,2.43E-3,2.39E-3,2.34E-3,2.31E-3,2.27E-3,2.24E-3,  FRESNL
     * 2.19E-3,2.15E-3,2.12E-3,2.10E-3,2.07E-3,2.05E-3,2.00E-3,1.95E-3,  FRESNL
     * 1.90E-3,1.56E-3,1.23E-3,9.68E-4,7.92E-4,6.52E-4,5.42E-4,4.65E-4,  FRESNL
     * 4.16E-4,3.76E-4,3.45E-4,3.38E-4,3.41E-4,3.59E-4,4.00E-4,4.52E-4,  FRESNL
     * 5.14E-4,6.17E-4,7.31E-4,9.00E-4,1.10E-3,0.0 /                     FRESNL
C                                                                        FRESNL
C         THE FORMULAS FOR THE REFLECTANCE ARE TAKEN FROM, E. G., D. H.  FRESNL
C         MENZEL (EDITOR), FUNDAMENTAL FORMULAS OF PHYSICS, (P. 422),    FRESNL
C         DOVER PUBLICATIONS, INC., NEW YORK, 1960.                      FRESNL
C                                                                        FRESNL
      WAVE = 1.0E+04/ZLAM                                                FRESNL
      IF( WAVE.GE.4000. )  GO TO 10                                      FRESNL
C         WX = FRACTIONAL NUMBER OF DATA POINTS CORRESPONDING TO WAVE.   FRESNL
      WX = 1.0 + (WAVE-2000.)/10.                                        FRESNL
      GO TO 20                                                           FRESNL
   10 WX = 201. + (WAVE-4000.)/50.                                       FRESNL
C         IJ = FIRST DATA-POINT INDEX ABOVE WAVE.                        FRESNL
   20 IJ = WX+1.0                                                        FRESNL
C         DELW = FRACTIONAL PART OF DATA INTERVAL CORRESPONDING TO WAVE. FRESNL
      DELW = WX - FLOAT(IJ-1)                                            FRESNL
      SN = SNNU(IJ-1) + (SNNU(IJ)-SNNU(IJ-1))*DELW                       FRESNL
      SK = SKNU(IJ-1) + (SKNU(IJ)-SKNU(IJ-1))*DELW                       FRESNL
      SNSQ = SIN( OMEGA )**2                                             FRESNL
      SNKS = SN*SN-SK*SK-SNSQ                                            FRESNL
      FNK = (2.*SN*SK)**2                                                FRESNL
      TRM = SQRT( SNKS*SNKS+FNK )                                        FRESNL
      SAPSQ = 0.50*(TRM+SNKS)                                            FRESNL
      SAMSQ = 0.50*(TRM-SNKS)                                            FRESNL
      CC = SAPSQ+SAMSQ                                                   FRESNL
      SAP = SQRT( SAPSQ )                                                FRESNL
      EE = COS( OMEGA )                                                  FRESNL
      EESQ = EE*EE                                                       FRESNL
      APE2 = 2.*SAP*EE                                                   FRESNL
      DD = SNSQ/EE                                                       FRESNL
      DDSQ = DD*DD                                                       FRESNL
      APD2 = 2.*SAP*DD                                                   FRESNL
      RS = (CC-APE2+EESQ)/(CC+APE2+EESQ)                                 FRESNL
      RHO = RS*(CC+DDSQ)/(CC+APD2+DDSQ)                                  FRESNL
      RETURN                                                             FRESNL
      END                                                                FRESNL
```

```
      SUBROUTINE GCRCLE(P1LAT,P1LON,P3LAT,P3LON,ALP13,ALP12,P2LAT,P2LON)
CCC
C        FOR THREE POINTS P1, P2, AND P3 ON A GREAT CIRCLE, SUBROUTINE
C        GCRCLE COMPUTES THE LATITUDE AND LONGITUDE OF THE INTER-
C        MEDIATE POINT P2, GIVEN THE LATITUDES AND LONGITUDES OF THE
C        END POINTS P1 AND P3, THE CENTRAL ANGLE ALP13 BETWEEN THE
C        CENTRAL RAYS TO P1 AND P3, AND THE CENTRAL ANGLE ALP12
C        BETWEEN THE CENTRAL RAYS TO P1 AND P2.
CCC
C        INPUT PARAMETERS
C        ARGUMENT LIST
C           P1LAT - NORTH LATITUDE OF POINT P1, RADIANS
C           P1LON - EAST LONGITUDE OF POINT P1, RADIANS
C           P3LAT - NORTH LATITUDE OF POINT P3, RADIANS
C           P3LON - EAST LONGITUDE OF POINT P3, RADIANS
C           ALP13 - EARTH-CENTRAL ANGLE BETWEEN RAYS TO POINTS
C                   P1 AND P3,  RADIANS
C           ALP12 - EARTH-CENTRAL ANGLE BETWEEN RAYS TO POINTS
C                   P1 AND P2,  RADIANS
CCC
C        OUTPUT PARAMETERS
C        ARGUMENT LIST
C           P2LAT - NORTH LATITUDE OF POINT P2, RADIANS
C           P2LON - EAST LONGITUDE OF POINT P2, RADIANS
CCC
      DATA  PI / 3.141592653590 /
CCC
C        CONSIDER THE SPHERICAL TRIANGLE P1-N-P3
C        POINT N IS NORTH POLE
CCC
      SINCOS = SIN(P3LAT) - COS(ALP13)*SIN(P1LAT)
      SINCOS = SINCOS/(SIN(ALP13)*COS(P1LAT))
      AMDA = ACOS( SINCOS )
CCC
C        CONSIDER THE SPHERICAL TRIANGLE P1-N-P2
CCC
      COSSIN = COS(ALP12)*SIN(P1LAT)
      SINCOS = SIN(ALP12)*COS(P1LAT)
      P2LAT = ASIN( COSSIN + SINCOS*COS(AMDA) )
CCC
C        AGAIN, CONSIDER SPHERICAL TRIANGLE P1-N-P2
CCC
      PI2 = PI+PI
      P3MP1 = P3LON-P1LON
      P12LON = ASIN( SIN(AMDA)*SIN(ALP12)/COS(P2LAT) )
      P2LON = P1LON + P12LON*SIGN(1.0,P3MP1)
      IF( ABS(P3MP1).LE.PI )  GO TO 10
      P2LON = P1LON - P12LON*SIGN(1.0,P3MP1)
   10 IF( P2LON.LT.0.0 )  P2LON = P2LON+PI2
      IF( P2LON.GE.PI2 )  P2LON = P2LON-PI2
      RETURN
      END
```

```
      SUBROUTINE GEOREA(HA1,GC1,GL1,HA2,GC2,GL2,SR21,EL21,AZ21)          GEOREA
CCC                                                                      GEOREA
C       SUBROUTINE GEOREA (A MODIFIED HARC ROUTINE), GIVEN THE           GEOREA
C       GEOGRAPHIC COORDINATES OF TWO POINTS, PROVIDES THE SLANT RANGE,  GEOREA
C       ELEVATION ANGLE, AND AZIMUTH ANGLE OF POINT 2 WITH RESPECT TO    GEOREA
C       POINT 1.                                                         GEOREA
CCC                                                                      GEOREA
C         INPUTS FROM CALL STATEMENT                                     GEOREA
C            HA1  = ALTITUDE OF POINT 1,  CM                             GEOREA
C            GC1  = COLATITUDE OF POINT 1,  RADIANS                      GEOREA
C            GL1  = EAST LONGITUDE OF POINT 1,  RADIANS                  GEOREA
C            HA2  = ALTITUDE OF POINT 2,  CM                             GEOREA
C            GC2  = COLATITUDE OF POINT 2,  RADIANS                      GEOREA
C            GL2  = EAST LONGITUDE OF POINT 2,  RADIANS                  GEOREA
C         OUTPUTS                                                        GEOREA
C            SR21 = SLANT RANGE OF POINT 2 RELATIVE TO POINT 1,  CM      GEOREA
C            EL21 = ELEVATION OF POINT 2 RELATIVE TO POINT 1,  RADIANS   GEOREA
C            AZ21 = AZIMUTH OF POINT 2 RELATIVE TO POINT 1,  RADIANS     GEOREA
CCC                                                                      GEOREA
      CALL GEOTAN(HA1,GC1,GL1,HA2,GC2,GL2,XE21,YN21,ZV21)                GEOREA
      XYSQ = XE21**2 + YN21**2                                           GEOREA
      SR21 = SQRT(XYSQ + ZV21**2)                                        GEOREA
      EL21 = ATAN2( ZV21,SQRT(XYSQ) )                                    GEOREA
      AZ21 = 0.0                                                         GEOREA
      IF( XYSQ.GT.0.0 )  AZ21 = ATAN2( XE21,YN21 )                       GEOREA
      RETURN                                                             GEOREA
      END                                                                GEOREA
```

```
      SUBROUTINE GEOTAN(HA1,GC1,GL1,HA2,GC2,GL2,XE21,YN21,ZV21)          GEOTAN
CCC                                                                      GEOTAN
C       SUBROUTINE GEOTAN (A MODIFIED HARC ROUTINE CALLED GEOXYZ),       GEOTAN
C       GIVEN THE GEOGRAPHIC COORDINATES OF TWO POINTS, PROVIDES THE     GEOTAN
C       TANGENT-PLANE COORDINATES OF POINT 2 WITH RESPECT TO POINT 1.    GEOTAN
CCC                                                                      GEOTAN
C         INPUTS FROM CALL STATEMENT                                     GEOTAN
C            HA1  = ALTITUDE OF POINT 1,  CM                             GEOTAN
C            GC1  = COLATITUDE OF POINT 1,  RADIANS                      GEOTAN
C            GL1  = EAST LONGITUDE OF POINT 1,  RADIANS                  GEOTAN
C            HA2  = ALTITUDE OF POINT 2,  CM                             GEOTAN
C            GC2  = COLATITUDE OF POINT 2,  RADIANS                      GEOTAN
C            GL2  = EAST LONGITUDE OF POINT 2,  RADIANS                  GEOTAN
C         OUTPUTS                                                        GEOTAN
C            XE21 = X COORDINATE OF POINT 2 RELATIVE TO POINT 1,  CM     GEOTAN
C            YN21 = Y COORDINATE OF POINT 2 RELATIVE TO POINT 1,  CM     GEOTAN
C            ZV21 = Z COORDINATE OF POINT 2 RELATIVE TO POINT 1,  CM     GEOTAN
CCC                                                                      GEOTAN
      DATA RE / 6.37103E+08 /                                            GEOTAN
CCC                                                                      GEOTAN
      GR1 = RE+HA1                                                       GEOTAN
      GR2 = RE+HA2                                                       GEOTAN
      GLD = GL2-GL1                                                      GEOTAN
      SINGC1 = SIN(GC1)                                                  GEOTAN
      SINGC2 = SIN(GC2)                                                  GEOTAN
      COSGC1 = COS(GC1)                                                  GEOTAN
      COSGC2 = COS(GC2)                                                  GEOTAN
      COSGLD = COS(GLD)                                                  GEOTAN
      XE21 = GR2*SINGC2*SIN(GLD)                                         GEOTAN
      YN21 = GR2*(SINGC1*COSGC2 - COSGC1*SINGC2*COSGLD)                  GEOTAN
      ZV21 = GR2*(COSGC1*COSGC2 + SINGC1*SINGC2*COSGLD) - GR1            GEOTAN
      RETURN                                                             GEOTAN
      END                                                                GEOTAN
```

```
      SUBROUTINE GEOXYZ(PH,PLAT,PLON,RPX,RPY,RPZ)
CCC
C        SUBROUTINE GEOXYZ CONVERTS THE GEOGRAPHIC COORDINATES OF A
C        POINT TO EARTH-CENTERED CARTESIAN COORDINATES.
CCC
C        INPUT PARAMETERS
C           ARGUMENT LIST
C                PH - ALTITUDE OF POINT P,  KM
C              PLAT - NORTH LATITUDE OF POINT P,  RADIANS
C              PLON - EAST LONGITUDE OF POINT P,  RADIANS
C        OUTPUT PARAMETERS
C           ARGUMENT LIST
C               RPX - EARTH-CENTERED CARTESIAN COORDINATE X OF
C                     POINT P,  KM
C               RPY - EARTH-CENTERED CARTESIAN COORDINATE Y OF
C                     POINT P,  KM
C               RPZ - EARTH-CENTERED CARTESIAN COORDINATE Z OF
C                     POINT P,  KM
CCC
      DATA  RE / 6.37103E+03 /
CCC
      RP = RE+PH
      RPZ = RP*SIN(PLAT)
      RPEQ = RP*COS(PLAT)
      RPX = RPEQ*COS(PLON)
      RPY = RPEQ*SIN(PLON)
      RETURN
      END
```

```
      SUBROUTINE GLITTR(THETAI,WIND,SPCULR,ZLAM,IDAY,IFIRES,ESURF1,
     *  SFR,EPSD)
CCC
C        SUBROUTINE GLITTR, CALLED FROM ESURF WHEN THE LINE-OF-SIGHT
C        INTERSECTS A WATER SURFACE, PROVIDES (1A) THE BIDIRECTIONAL
C        REFLECTANCE-DISTRIBUTION FUNCTION (BRDF) AND (1B) DIRECTIONAL
C        EMISSIVITY OF THE WATER SURFACE AT THE INTERSECTION POINT OF
C        THE OPTICAL LINE-OF-SIGHT FROM THE DETECTOR AND  (2) THE
C        GEOGRAPHIC COORDINATES (NORTH LATITUDE AND EAST LONGITUDE) OF
C        THE POINT ON A SMOOTH HORIZONTAL SURFACE FOR A SPECULAR
C        REFLECTION OF A RAY FROM THE SOURCE TO THE DETECTOR, IF
C        REQUESTED (BY LOGICAL PARAMETER SPCULR = .TRUE. IN ARGUMENT
C        LIST).  ONLY THE DIRECTIONAL EMISSIVITY IS PROVIDED IF THERE
C        IS NO SOURCE.
CCC
C * *    INPUT PARAMETERS
C        ARGUMENT LIST
C           THETAI = ZENITH ANGLE OF SOURCE (SUN OR FIREBALL) AT THE
C                    INTERSECTION POINT OF LINE-OF-SIGHT FROM DETECTOR
C                    TO EARTH'S SURFACE  (RADIANS)
C             WIND = WIND SPEED AT 41 FEET ABOVE SEA LEVEL (METERS/SEC)
C           SPCULR = LOGICAL PARAMETER
C                  = .TRUE.  COMPUTE COORDINATES OF SPECULAR
C                            REFLECTION POINT
C                  = .FALSE. DO NOT COMPUTE COORDINATES OF SPECULAR
C                            REFLECTION POINT
C             ZLAM = WAVELENGTH  (MICROMETERS)
C             IDAY = INDEX FOR DAYLIGHT CONDITIONS AT POINT P
C                  = 0  IF SOLAR ZENITH ANGLE .GT. 90 DEGREES
C                  = 1  IF SOLAR ZENITH ANGLE .LE. 90 DEGREES
C           IFIRES = FLAG FOR INCLUSION OF FIREBALLS
C                  = 0  IF NO FIREBALL IS BEING CONSIDERED
C                  .GT. 0  IF FIREBALLS ARE BEING CONSIDERED
C           ESURF1 = LOGICAL PARAMETER
C                  = .TRUE.  IF ESURF IS CALLED FOR THE FIRST TIME FROM
C                            SURRAD AND EPSD IS WANTED AS AN OUTPUT,
C                            WHICH IS ALWAYS THE CASE IN THE NBR MODULE
C                  = .FALSE. IF ESURF IS NOT BEING CALLED FOR THE FIRST
C                            TIME FROM SURRAD AND A RECOMPUTATION OF
C                            EPSD IS NOT NEEDED
C        TECTOR COMMON
C           DETLAT - DETECTOR NORTH LATITUDE, RADIANS
C           DETLON - DETECTOR EAST LONGITUDE, RADIANS
C           DETALT - DETECTOR ALTITUDE, KM
C           DETZEN - DETECTOR ZENITH ANGLE AT POINT P,  RADIANS
C        POSITN COMMON
C           POSLAT - NORTH LATITUDE OF INTERSECTION POINT OF LINE-OF-
C                    SIGHT FROM DETECTOR  TO EARTH'S SURFACE  (RADIANS)
C           POSLON - EAST LONGITUDE OF INTERSECTION POINT OF LINE-OF-
C                    SIGHT FROM DETECTOR  TO EARTH'S SURFACE  (RADIANS)
C           POSALT - ALTITUDE OF POINT P AT WHICH LINE-OF-SIGHT
C                    INTERSECTS EARTH'S SURFACE, KM
C        SOURCE COMMON
C           SRCLAT - NORTH LATITUDE OF SOURCE (SUN OR FIREBALL) RADIANS
C           SRCLON - EAST LONGITUDE OF SOURCE  (RADIANS)
C           SRCALT - ALTITUDE OF SOURCE, IF NOT THE SUN  (KM)
C           SRCFLG - 1, IF SOURCE IS SUN
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C                 - 2, IF SOURCE IS FIREBALL
C * *     OUTPUT PARAMETERS
C         ARGUMENT LIST
C               SFR - F SUB R (2,D(2),ZLAM,THETAI,THETAR)      (1/SR)
C                   - BIDIRECTIONAL REFLECTANCE-DISTRIBUTION FUNCTION
C                     FOR A WIND-RUFFLED SURFACE.
C              EPSD - ( 1.0-RHO(THETAR) )     (DIMENSIONLESS)
C                   - DIRECTIONAL EMISSIVITY, WHERE RHO(THETAR) IS THE
C                     SPECULAR REFLECTANCE AT ZENITH ANGLE THETAR
C                     FOR A SMOOTH HORIZONTAL SURFACE.
C         POSITN COMMON
C            (THIS OUTPUT OBTAINS ONLY IF SPCULR=.TRUE.)
C            SPCLAT - NORTH LATITUDE OF POINT ON SMOOTH HORIZONTAL
C                     SURFACE FOR A SPECULAR REFLECTION FROM THE
C                     SOURCE TO THE DETECTOR,  RADIANS
C            SPCLON - EAST LONGITUDE OF POINT ON SMOOTH HORIZONTAL
C                     SURFACE FOR A SPECULAR REFLECTION FROM THE
C                     SOURCE TO THE DETECTOR,  RADIANS
CCC
      COMMON/POSITN/  POSLAT,POSLON,POSALT,SPCLAT,SPCLON
     $                ,C12LAT,C12LON,C12ALT
      COMMON/SOURCE/  SRCLAT,SRCLON,SRCALT,SRCFLG,SRCZEN(11),SRCSR(11)
      COMMON/TECTOR/  DETLAT,DETLON,DETALT,DETZEN,DETAZI(11)
      LOGICAL  SPCULR,ESURFI
      DATA  PI,RE / 3.141592653590,6.37103E+03 /
      DATA  RSUN,EPSILN / 1.495979E+08,4.6524E-03 /
CC
CC        NEED NOT COMPUTE SFR IF NEITHER SUN NOR FIREBALL IS CONSIDERED
CC        AS A SOURCE, SO SET IT AS WELL AS THE COORDINATES OF THE
CC        SPECULAR POINT (ARBITRARILY) TO -1.0
      IF( (IDAY.EQ.1) .OR. (IFIRES.GT.0) )  GO TO 8
      SFR = -1.0
      DTZENP = DETZEN
      GO TO 70
CC
CCC       FORMULAS FOR SFR * * * * * * * * * * * * * * * * * * * * * * * *
CCC       FIRST, FOR TILTED FACET AT POINT P, USE LEVANON'S EQUATIONS
CCC       FOR TOTAL TILT MAGNITUDE (BETA) AND DIRECTION (THETA,PHI) AND
CCC       ANGLE OF INCIDENCE (OMEGA).  WE USE HIS EQUATIONS REWRITTEN IN
CCC       TERMS OF OUR PARAMETER EPSA.
CC
    8 EPSA = (RE+POSALT)/(RE+DETALT)
CC
CC        THETAP - NORTH LATITUDE OF POINT P RELATIVE TO DETECTOR
      THETAP = POSLAT-DETLAT
      CSTHTP = COS(THETAP)
CC
CC        PHIP = EAST LONGITUDE OF POINT P RELATIVE TO DETECTOR
      PHIP = POSLON-DETLON
      CSPHIP = COS(PHIP)
CC
CC        PHIL = EAST LONGITUDE OF POINT Q-SUB-L RELATIVE TO DETECTOR
CC               (LEVANON (LE-71B) EQ. (1)).
CC               POINT Q-SUB-L IS DEFINED BY THE SEA SURFACE AND A
CC               VECTOR, STARTING FROM THE EARTH'S CENTER, PARALLEL TO
CC               THE RAY FROM THE DETECTOR TO THE REFLECTION POINT P.
      EPTHTP = EPSA*CSTHTP
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      PHIL = ATAN( -EPTHTP*SIN(PHIP)/(1.-EPTHTP*CSPHIP) )           GLITTR
CC        THETAL = NORTH LATITUDE OF POINT Q-SUB-L RELATIVE TO DETECTOR  GLITTR
CC                 (LEVANON EQ. (2)).                                    GLITTR
      ROOT = SQRT( 1.0-2.*EPTHTP*CSPHIP+EPTHTP*EPTHTP )              GLITTR
      THETAL = ATAN( -EPSA*SIN(THETAP)/ROOT )                         GLITTR
      CSTHTL = COS(THETAL)                                            GLITTR
CC                                                                   GLITTR
CC        THETAS = NORTH LATITUDE OF SOURCE RELATIVE TO DETECTOR     GLITTR
      THETAS = SRCLAT-DETLAT                                          GLITTR
      CSTHTS = COS(THETAS)                                            GLITTR
CC        PHIS = EAST LONGITUDE OF SOURCE RELATIVE TO DETECTOR       GLITTR
      PHIS = SRCLON-DETLON                                            GLITTR
CC                                                                   GLITTR
CC        PHIN = EAST LONGITUDE OF POINT Q-SUB-N RELATIVE TO DETECTOR   GLITTR
CC               (LEVANON EQ. (3)).                                   GLITTR
CC               POINT Q-SUB-N IS DEFINED BY THE SEA SURFACE AND A    GLITTR
CC               VECTOR, STARTING FROM THE EARTH'S CENTER, PARALLEL TO   GLITTR
CC               THE NORMAL REQUIRED FOR REFLECTION FROM POINT P.     GLITTR
      AAA = CSTHTL*SIN(PHIL) + CSTHTS*SIN(PHIS)                       GLITTR
      BBB = CSTHTL*COS(PHIL) + CSTHTS*COS(PHIS)                       GLITTR
      PHIN = ATAN( AAA/BBB )                                          GLITTR
CC        THETAN = NORTH LATITUDE OF POINT Q-SUB-N RELATIVE TO DETECTOR  GLITTR
CC                 (LEVANON EQ. (4)).                                    GLITTR
      ROOT = CSTHTL*CSTHTL + CSTHTS*CSTHTS + 2.*CSTHTL*CSTHTS*        GLITTR
     $       COS(PHIL-PHIS)                                           GLITTR
      THETAN = ATAN( (SIN(THETAL)+SIN(THETAS))/SORT(ROOT) )           GLITTR
CC                                                                   GLITTR
CC        PHI = TILT TOWARD THE EAST AT THE REFLECTION POINT P       GLITTR
CC              (LEVANON EQ. (5)).                                    GLITTR
      PHI = PHIN-PHIP                                                 GLITTR
CC        THETA = TILT TOWARD THE NORTH AT THE REFLECTION POINT P    GLITTR
CC              (LEVANON EQ. (6)).                                    GLITTR
      THETA = THETAN-THETAP                                           GLITTR
CC                                                                   GLITTR
CC        BETA = TOTAL TILT MAGNITUDE AT THE REFLECTION POINT P      GLITTR
CC              (LEVANON EQ. (7)).                                    GLITTR
      ROOT = TAN(THETA)**2 + TAN(PHI)**2                              GLITTR
      BETA = ATAN( SQRT(ROOT) )                                       GLITTR
CC                                                                   GLITTR
CC        OMEGA = ANGLE OF INCIDENCE AT REFLECTION POINT P           GLITTR
CC              (LEVANON EQ. (8)).                                    GLITTR
      ROOT = TAN(THETAN-THETAS)**2 + TAN(PHIN-PHIS)**2                GLITTR
      OMEGA = ATAN( SQRT(ROOT) )                                      GLITTR
CC                                                                   GLITTR
CC        SIGSQ = MEAN SQUARE SLOPE REGARDLESS OF DIRECTION          GLITTR
      SIGSO = (3.0 + 5.12*WIND)*1.E-03                                GLITTR
CC                                                                   GLITTR
CC        SMALLP = PROBABILITY FOR OCCURRENCE OF SLOPE BETA          GLITTR
      TBETA = TAN(BETA)                                               GLITTR
      SMALLP = EXP( -TBETA*TBETA/SIGSO )/(PI*SIGSQ)                   GLITTR
CC                                                                   GLITTR
      CALL FRESNL(ZLAM,OMEGA,RHO)                                     GLITTR
CC        NOW HAVE FRESNEL MONOCHROMATIC REFLECTANCE (RHO)           GLITTR
CC                                                                   GLITTR
CC        IN COMPUTING SFR, TO AVOID POSSIBLE DIVISION BY ZERO OR    GLITTR
CC        NEAR-ZERO IF THETAI OR DETZEN EXCEEDS AN ARBITRARILY-      GLITTR
CC        SELECTED VALUE, 89.9 DEG., RESET THETAI AND/OR DETZEN TO 89.9  GLITTR
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CC        DEG.  DEFINE TEMPORARY VARIABLES TO AVOID ALTERING
CC        ORIGINAL VARIABLES.
      IWARN = 0
      THTAIP = THETAI
      DTZENP = DETZEN
      PID2 = 0.50*PI
      DELTHI = PID2-THETAI
      DELTHR = PID2-DETZEN
      IF( DELTHI.GE.1.745E-03 )  GO TO 101
      THTAIP = PID2-1.745E-03
      IWARN = 1
  101 IF( DELTHR.GE.1.745E-03 )  GO TO 102
      DTZENP = PID2-1.745E-03
      IWARN = 1
  102 IF( IWARN.EQ.0 )  GO TO 104
CC    WRITE(6,103)
  103 FORMAT (1H0,9X,44H *** NOTE ***  FROM SUBROUTINE GLITTR  ***  /
     1 10X,55HTHETAI OR DETZEN EXCEEDS AN ARBITRARILY-SELECTED VALUE,/
     2 10X,55H89.9 DEGREES, TO WHICH THETAI OR DETZEN HAS BEEN RESET /
     3 10X,55HTO AVOID POSSIBLE DIVISION BY ZERO OR NEAR-ZERO IN     /
     4 10X,15HCOMPUTING SFR. /
     5 10X,30HUSER SHOULD VERIFY THAT---    /
     6 10X,55H   (1) THE CODE HAS A PROPER VALUE OF THETAI OR DETZEN /
     7 10X,20H        AND, IF SO,  /
     8 10X,55H   (2) WHETHER OR NOT RESETTING OF THETAI OR DETZEN    /
     9 10X,40H        TO 89.9 DEGREES IS SATISFACTORY. )
CC
  104 SHADOW = 1.0
      IF( WIND.EQ.0.0 )  GO TO 107
CC        SHADOW = SHADOWING FACTOR BASED ON WORK OF SAUNDERS (SA-67,
CC                 SA-68C) BUT EXTENDED TO PERMIT A BISTATIC DEPENDENCE
CC                 ON THE ZENITH ANGLES OF BOTH INCOMING AND OUTGOING
CC                 RAYS
      PISQ = SQRT( PI )
      SIGS = SQRT( 5.12E-03*WIND )
      THETV2 = ATAN2( 0.50,SIGS )
CC        THETV2 IS THE ZENITH ANGLE BELOW WHICH ESSENTIALLY
CC        NO SHADOWING OCCURS.
      SOFSVI = 1.0
      IF( THETAI.LT.THETV2 )  GO TO 105
      SVI = 1.0/(SIGS*TAN(THTAIP))
      SOFSVI = 2.0/(1.0+ERF(SVI)+EXP(-SVI*SVI)/(PISQ*SVI))
  105 SOFSVR = 1.0
      IF( DETZEN.LT.THETV2 )  GO TO 106
      SVR = 1.0/(SIGS*TAN(DTZENP))
      SOFSVR = 2.0/(1.0+ERF(SVR)+EXP(-SVR*SVR)/(PISQ*SVR))
  106 SHADOW = SOFSVI*SOFSVR
CC
  107 SFR = 0.25*RHO*SMALLP/(COS(DTZENP)*COS(THTAIP))
      SFR = SFR*SHADOW/COS(BETA)**4
CC
CC
CC
      IF( .NOT.SPCULR )  GO TO 70
CC
CCC       FORMULAS FOR SPCLAT AND SPCLON * * * * * * * * * * * * * * * *
CC
```

```
CC        ALP = TOTAL EARTH-CENTRAL ANGLE BETWEEN RAYS TO DETECTOR    GLITTR
CC        AND SOURCE.                                                 GLITTR
      ALP = CANGLE(DETLAT,DETLON,SRCLAT,SRCLON)                       GLITTR
      KFLG = SRCFLG+0.05                                              GLITTR
      GO TO (10,12), KFLG                                             GLITTR
CC        SET EPSS FOR SUN BEING SOURCE.                              GLITTR
   10 EPSS = (RE+POSALT)/RSUN                                         GLITTR
      GO TO 14                                                        GLITTR
CC        SET EPSS FOR FIREBALL BEING SOURCE.                         GLITTR
   12 EPSS = (RE+POSALT)/(RE+SRCALT)                                  GLITTR
C * * *                                                               GLITTR
C * * *   START OF ITERATIVE PROCEDURE FOR THE SOLUTION OF THE        GLITTR
C         REFLECTION POINT (IN TERMS OF ALPA AND ALPS).               GLITTR
C         THE METHOD USED IS  NEWTON-RAPHSON.                         GLITTR
C * * *                                                               GLITTR
   14 KOUNT = 0                                                       GLITTR
      FACT = (1.0-EPSA)/((1.0-EPSA)+(1.0-EPSS))                       GLITTR
C         THE INITIAL GUESS FOR ALPA IS GIVEN BY  FACT*ALP            GLITTR
      ALPA = FACT*ALP                                                 GLITTR
   16 KOUNT = KOUNT+1                                                 GLITTR
      ALPS = ALP-ALPA                                                 GLITTR
      BETA = ATAN( EPSA*SIN(ALPA)/(1.0-EPSA*COS(ALPA)) )              GLITTR
      BETS = ATAN( EPSS*SIN(ALPS)/(1.0-EPSS*COS(ALPS)) )              GLITTR
C         CALCULATE F(ALPA), FOFA, AND F PRIME(ALPA), FOFAP           GLITTR
      FOFA = ALP-2.*ALPA+BETS-BETA                                    GLITTR
      DD1 = 1.0 + EPSS*(EPSS-2.*COS(ALPS))                            GLITTR
      DD2 = 1.0 + EPSA*(EPSA-2.*COS(ALPA))                            GLITTR
      FOFAP = EPSS*(EPSS-COS(ALPS))/DD1 - 2.0                         GLITTR
      FOFAP = EPSA*(EPSA-COS(ALPA))/DD2 + FOFAP                       GLITTR
      DELTA = (ALPA+BETA)-(ALPS+BETS)                                 GLITTR
C         UPDATE ALPA --                                              GLITTR
C         ALPA NEW = ALPA OLD - F(ALPA OLD)/F PRIME( ALPA OLD)        GLITTR
      ALPA = ALPA-FOFA/FOFAP                                          GLITTR
C         CHECK FOR SOLUTION OR IF NUMBER OF ALLOWED ITERATIONS       GLITTR
C         HAS BEEN EXCEEDED                                           GLITTR
      IF( ABS(DELTA).LE.2.0E-05 )  GO TO 18                           GLITTR
      IF( KOUNT.GE.100 )  GO TO 18                                    GLITTR
      GO TO 16                                                        GLITTR
C * * *                                                               GLITTR
C * * *   END OF ITERATIVE PROCEDURE.                                 GLITTR
C * * *                                                               GLITTR
   18 ALPS = ALP-ALPA                                                 GLITTR
      ALPSD = ALPS*180./PI                                            GLITTR
      ALPAD = ALPA*180./PI                                            GLITTR
      WRITE(6,5)  ALPAD,ALPSD,KOUNT,EPSA,EPSS                         GLITTR
    5 FORMAT (12HO  ALPHA A =,F12.4,5X,11H  ALPHA S =,F12.4,5X,I5,    GLITTR
     *  12H  ITERATIONS,5X,6H EPSA=,E12.4,5X,6H EPSS=,E12.4)          GLITTR
      CALL GCRCLE(DETLAT,DETLON,SRCLAT,SRCLON,ALP,ALPA,SPCLAT,SPCLON) GLITTR
CC        NOW HAVE SPCLAT AND SPCLON                                  GLITTR
CC                                                                    GLITTR
      GO TO 80                                                        GLITTR
   70 SPCLAT = -1.0                                                   GLITTR
      SPCLON = -1.0                                                   GLITTR
   80 IF( .NOT.ESURFI )  RETURN                                       GLITTR
CC                                                                    GLITTR
CCC       FORMULAS FOR EPSD * * * * * * * * * * * * * * * * * * * * * GLITTR
CC                                                                    GLITTR
      CALL FRESNL(ZLAM,DTZENP,RHO)                                    GLITTR
CC                                                                    GLITTR
CC        COMPUTE EPSD                                                GLITTR
      EPSD = 1.0-RHO                                                  GLITTR
      RETURN                                                          GLITTR
      END                                                             GLITTR
```

```
      SUBROUTINE PATH( FIRST, ISHELL, DS, XFRACS )
C
C        *PATH* DEVELOPS THE PATH INTEGRALS FOR ATMOSPHERIC ABSORPTION.
C
CLJ
CLJ   INPUT PARAMETERS
CLJ      ARGUMENT LIST
CLJ           FIRST = LOGICAL INITIALIZATION SWITCH
CLJ                 = .TRUE. FOR FIRST CALL (I.E., CORRESPONDING TO
CLJ                   PATH FROM RX TO RY IN TRNSCO)
CLJ                 = .FALSE. FOR SUBSEQUENT CALLS (I.E., CORRESPONDING
CLJ                   TO PATH FROM RY TO RZ IN TRNSCO)
CLJ       ISHELL(1) = INDX(I) IN CALL FROM TRNSCO OR SURRAD
CLJ       ISHELL(2) = INDX(I+1) IN CALL FROM TRNSCO OR SURRAD
CLJ              DS = DS(I+1) IN CALL FROM TRNSCO OR SURRAD.
CLJ                   NOTE... IT IS ALWAYS TRUE THAT DS(1)=0.0 AND
CLJ                   DS(NC+1)=-1., WHERE NC IS THE NUMBER OF PATH
CLJ                   SEGMENTS PLUS ONE.  ATMRAD WILL NOT BE CALLED
CLJ                   WITH I=NC.
CLJ       XFRACS(1) = XFRACS(I) IN CALL FROM TRNSCO OR SURRAD
CLJ       XFRACS(2) = XFRACS(I+1) IN CALL FROM TRNSCO OR SURRAD.
CLJ                   NOTE. THIS ARRAY XFRACS (DIMENSIONED 2) IS NOT THE
CLJ                   SAME AS THE ARRAY XFRACS (DIMENSIONED 100) IN
CLJ                   SUBROUTINES STEP, STEPS, AND TRNSCO.
CLJ                   ( SEE NOTE IN SUBROUTINE ATMRAD )
CLJ      XYZCOM COMMON
CLJ              NS = NUMBER OF ALTITUDE BOUNDARIES
CLJ           TS(J) = TEMPERATURE AT ALTITUDE BOUNDARY J, DEG K (J=1,NS)
CLJ           PS(J) = PRESSURE AT ALTITUDE BOUNDARY J, ATM  (J=1,NS)
CLJ     XNSPEC(J,N) = SPECIES-N DENSITY AT ALTITUDE BOUNDARY J, 1/CM**3
CLJ                   (J=1,NS , N=1,10)
CLJ   OUTPUT PARAMETERS
CLJ      XYZCOM COMMON
CLJ        U(I,N,2) = CUMULATIVE VALUE OF PATH PARAMETER U (AREAL
CLJ                   DENSITY) FOR TEMPERATURE-INDEX I AND SPECIES N AT
CLJ                   END OF LINE SEGMENT DS,   CM AT STP
CLJ       UP(I,N,2) = CUMULATIVE VALUE OF PATH PARAMETER UP (PRODUCT OF
CLJ                   U AND PRESSURE P) FOR TEMPERATURE INDEX I AND
CLJ                   SPECIES N AT END OF LINE SEGMENT DS,  ATM-CM
CLJ                   AT STP         FOR U AND UP  (I=1,2 , N=1,10)
CLJ
      DIMENSION XNS1(10), XNS2(10), DU(10,10), DUP(10,10), ISHELL(2),
     1          XFRACS(2)
      COMMON / XYZCOM / ITMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81),
     1                  XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS,
     2                  FACT
C
      LOGICAL FIRST
C
CLJ         XINTRP IS AN ARITHMETIC STATEMENT FUNCTION FOR LINEAR
CLJ         INTERPOLATION, RETURNING THE VALUE XINTRP AT A FRACTIONAL
CLJ         DISTANCE (1.-XFRAC) BETWEEN END-POINT VALUES Z1 AND Z2.
CLJ
      XINTRP( Z1, Z2 ) = Z1 * XFRAC + Z2 * ( 1. - XFRAC )
C
      IF ( .NOT. FIRST ) GO TO 1
C        INITIALIZATIONS
```

```
      FIRST = .FALSE.
CLJ       NOW ZERO SECOND-HALVES OF U AND UP ARRAYS, WHICH IS WHERE WE
CLJ       ACCUMULATE OUR OUTPUT RESULTS FOR THESE ARRAYS.
      CALL XMIT ( -100, 0., U(1,1,2) )
      CALL XMIT ( -100, 0., UP(1,1,2) )
C
    1 L1 = ISHELL(1)
      L2 = ISHELL(2)
C         SET SHELL PROPERTIES AT FIRST POINT
CLJ       NOW TRANSFER SECOND-HALVES OF U AND UP ARRAYS TO FIRST-HALVES,
CLJ       I.E., INITIALIZE THE STARTING POINT OF THE SECOND LEG TO
CLJ       VALUES AT END OF FIRST LEG OF PATH.
      CALL XMIT ( 100, U(1,1,2), U )
      CALL XMIT ( 100, UP(1,1,2), UP )
      IF ( L2 .EQ. 0 ) RETURN
C         INTERPOLATE FOR P, T, AND C(SPECIES) AT FIRST POINT
      XFRAC = XFRACS(1)
      PSL1 = PS(L1)
      TSL1 = TS(L1)
      IF ( XFRAC .EQ. 1. ) GO TO 2
      PSL1 = XINTRP( PS(L1), PS(L2) )
      TSL1 = XINTRP( TS(L1), TS(L2) )
    2 DO 3 N=1,10
      XNS1(N) = XNSPEC(L1,N)
      IF ( XFRAC .EQ. 1.  .OR.  XNSPEC(L1,N) + XNSPEC(L2,N) .EQ. 0. )
     $     GO TO 3
      XNS1(N) = XINTRP( XNSPEC(L1,N), XNSPEC(L2,N) )
    3 CONTINUE
C         INTERPOLATE FOR P, T, AND C(SPECIES) AT SECOND POINT
      XFRAC = XFRACS(2)
      PSL2 = PS(L2)
      TSL2 = TS(L2)
      IF ( XFRAC .EQ. 1. ) GO TO 4
      PSL2 = XINTRP( PS(L2), PS(L1) )
      TSL2 = XINTRP( TS(L2), TS(L1) )
    4 DO 5 N=1,10
      XNS2(N) = XNSPEC(L2,N)
      IF ( XFRAC .EQ. 1.  .OR.  XNSPEC(L1,N) + XNSPEC(L2,N) .EQ. 0. )
     $     GO TO 5
      XNS2(N) = XINTRP( XNSPEC(L2,N), XNSPEC(L1,N) )
    5 CONTINUE
C         COMPUTE DIFFERENTIAL U AND UP
      CALL SEGMENT ( 10, 0., XNS1, PSL1, TSL1, DS, XNS2, PSL2, TSL2,
     $               DU, DUP )
C         ACCUMULATE U AND UP AT SECOND POINT
      DO 6 N=1,10
      DO 6 I=1,2
      U(I,N,2) = U(I,N,2) + DU(I,N)
      UP(I,N,2) = UP(I,N,2) + DUP(I,N)
    6 CONTINUE
      RETURN
      END
```

```
      FUNCTION PLANCK ( T, W )
C
C        *PLANCK* GIVES THE BLACK BODY SPECTRUM
C        ( WATTS CM-2 ST-1 (CM-1)-1 )
C
CLJ
CLJ   INPUT PARAMETER
CLJ      ARGUMENT LIST
CLJ               T = TEMPERATURE, DEG K
CLJ               W = WAVENUMBER, 1/CM
CLJ      DATA STATEMENTS
CLJ               C = VELOCITY OF LIGHT, CM/SEC
CLJ               H = PLANCK'S CONSTANT, J SEC
CLJ             CHK = C*H/K, CM DEGREE-K
CLJ                   WHERE K = BOLTZMANN CONSTANT
CLJ                           = 1.380662E-23 J/(DEGREE-K)
CLJ   OUTPUT PARAMETER
CLJ      FUNCTION
CLJ          PLANCK = SPECTRAL RADIANCE, WATTS/(CM**2 SR CM**-1)
CLJ
      DATA C / 2.997925E10 /, CHK / 1.438786 /, H / 6.626176E-34 /
CLJ
      PLANCK = 0.
      IF ( T .EQ. 0. ) GO TO 2
      Z = CHK / T * W
      IF ( Z .GE. 88. ) GO TO 2
      PLANCK = ( 2. * C**2 * W**3 / ( EXP(Z) - 1. ) ) * H
CLJ
CLJ       TO OBTAIN PLANCK IN THE UNITS USED BY GRC,
CLJ                 PHOTONS/(CM**2 SEC SR CM**-1),
CLJ       DIVIDE BY HCW=H*C*W .
CLJ
CLJ       TO OBTAIN PLANCK IN UNITS OF W/(CM**2 SR MICRON), MULTIPLY BY
CLJ       1.E-04*W*W OR BY 1.E+04/(ZLAMDA*ZLAMDA) WHERE ZLAMDA=1.E+04/W
CLJ
    2 RETURN
      END
```

```
      SUBROUTINE REATAN(SR,EL,AZ,XE,YN,ZV)
CCC
C        SUBROUTINE REATAN (A MODIFIED HARC ROUTINE CALLED REAXYZ),
C        GIVEN THE SLANT RANGE, ELEVATION ANGLE, AND AZIMUTH ANGLE OF A
C        POINT WITH RESPECT TO SOME REFERENCE LOCATION, PROVIDES THE
C        TANGENT-PLANE COORDINATES OF THE POINT WITH RESPECT TO THE
C        SAME REFERENCE.
CCC
C          INPUTS FROM CALL STATEMENT
C             SR    = SLANT RANGE OF POINT,  CM
C             EL    = ELEVATION ANGLE OF POINT,  RADIANS
C             AZ    = AZIMUTH ANGLE OF POINT,  RADIANS
C          OUTPUTS
C             XE    = X COORDINATE OF POINT,  CM
C             YN    = Y COORDINATE OF POINT,  CM
C             ZV    = Z COORDINATE OF POINT,  CM
CCC
      COSEL = COS(EL)
      XE = SR*COSEL*SIN(AZ)
      YN = SR*COSEL*COS(AZ)
      ZV = SR*SIN(EL)
      RETURN
      END
```

```
      SUBROUTINE RINOUT(MAT,IFIRE,IDAY)
CCC
C        SUBROUTINE RINOUT, GIVEN THE GEOGRAPHIC LOCATIONS OF THE
C        SOURCES (SUN AND/OR FIREBALLS), THE DETECTOR, AND THE
C        POSITION P OF THE INTERSECTION OF THE LINE-OF-SIGHT FROM THE
C        DETECTOR TO THE EARTH'S SURFACE, COMPUTES THE ZENITH ANGLES
C        (AND, FOR FIREBALLS, SLANT RANGES) OF SOURCES FROM P AND THE
C        DIRECTION OF THE RAY FROM P TO DETECTOR IN TERMS OF ZENITH
C        ANGLE OF THE DETECTOR AND (IF THE SURFACE IS NOT LAMBERTIAN
C        (MAT=1) OR WATER (MAT=2)) THE ABSOLUTE VALUE OF THE AZIMUTH
C        ANGLE OF SCATTER WITH RESPECT TO THE PRINCIPAL PLANE
C        CONTAINING THE INCOMING RAY.
CCC
CCC      INPUT PARAMETERS
C        ARGUMENT LIST
C            IFIRE = NUMBER OF FIREBALLS TO BE CONSIDERED AS SOURCES
C                    (ALWAYS ZERO IN NBR MODULE)
C              MAT = INDEX FOR CATEGORY OF SURFACE MATERIAL
C                  = 1, LAMBERTIAN DIFFUSE SURFACE   = 2, WATER
C                  = 3, SNOW   = 4, SAND   = 5, SOIL   = 6, FOLIAGE
C                  = 7, URBAN MATERIAL
C        TECTOR COMMON
C           DETLAT - NORTH LATITUDE OF DETECTOR SUBPOINT, RADIANS
C           DETLON - EAST LONGITUDE OF DETECTOR SUBPOINT, RADIANS
C           DETALT - ALTITUDE OF DETECTOR, KM
C        FIRBAL COMMON (NOT USED IN NBR MODULE)
C            FBLAT(L) - NORTH LATITUDE OF FIREBALL-L, RADIANS
C            FBLON(L) - EAST LONGITUDE OF FIREBALL-L, RADIANS
C            FBALT(L) - ALTITUDE OF FIREBALL-L, KM
C           FBRINT(L) - RADIANT INTENSITY OF FIREBALL-L, WATTS/SEC
C        POSITN COMMON
C           POSLAT - NORTH LATITUDE OF INTERSECTION POINT OF LINE-OF-
C                    SIGHT FROM DETECTOR TO EARTH'S SURFACE, RADIANS
C           POSLON - EAST LONGITUDE OF INTERSECTION POINT OF LINE-OF-
C                    SIGHT FROM DETECTOR TO EARTH'S SURFACE, RADIANS
C           POSALT - ALTITUDE OF INTERSECTION POINT OF LINE-OF-SIGHT
C                    FROM DETECTOR TO EARTH'S SURFACE, KM
C        SOLARP COMMON
C           SOLLAT - NORTH LATITUDE OF SUBSOLAR POINT, RADIANS
C           SOLLON - EAST LONGITUDE OF SUBSOLAR POINT, RADIANS
CCC      OUTPUT PARAMETERS
C        ARGUMENT LIST
C             IDAY - INDEX FOR DAYLIGHT CONDITIONS AT POINT P
C                  =0 IF SOLAR ZENITH ANGLE .GT. 90. DEGREES
C                  =1 IF SOLAR ZENITH ANGLE .LE. 90. DEGREES
C        TECTOR COMMON
C           DETZEN - ZENITH ANGLE OF RAY REFLECTED AT POINT P TOWARD
C                    THE DETECTOR, RADIANS
C           DETAZI(1) - ABSOLUTE VALUE OF AZIMUTH OF REFLECTED RAY,
C                       MEASURED FROM PRINCIPAL PLANE DETERMINED BY
C                       VERTICAL PLANE THROUGH INCOMING RAY FROM SUN,
C                       RADIANS
C           DETAZI(L+1), L=1,IFIRE   (NOT USED IN NBR MODULE)
C                  - ABSOLUTE VALUE OF AZIMUTH OF REFLECTED RAY,
C                    MEASURED FROM PRINCIPAL PLANE DETERMINED BY
C                    VERTICAL PLANE THROUGH INCOMING RAY, RADIANS
C        SOURCE COMMON
```

```
C          SRCZEN(1) - ZENITH ANGLE OF RAY INCOMING TO POINT P FROM     RINOUT    59
C                      THE SUN, RADIANS                                  RINOUT    60
C          SRCZEN(L+1), L=1,IFIRE   (NOT USED IN NBR MODULE)            RINOUT    61
C                     - ZENITH ANGLE OF RAY INCOMING TO POINT P FROM    RINOUT    62
C                      FIREBALL-L, RADIANS                               RINOUT    63
C           SRCSR(L+1), L=1,IFIRE   (NOT USED IN NBR MODULE)            RINOUT    64
C                     - SLANT RANGE FROM FIREBALL-L TO POINT P, KM      RINOUT    65
CCC                                                                      RINOUT    66
      COMMON/FIRBAL/  FBLAT(10),FBLON(10),FBALT(10),FBRINT(10)           FIRBAL     2
      COMMON/POSITN/  POSLAT,POSLON,POSALT,SPCLAT,SPCLON                 POSITN     2
     $               ,C12LAT,C12LON,C12ALT                               POSITN     3
      COMMON/SATELL/  SATLAT,SATLON,SATALT,SATZEN,SATAZI                 SATELL     2
      COMMON/SOLARP/  SOLLAT,SOLLON,SOLIRR(10)                           SOLARP     2
      COMMON/SOURCE/  SRCLAT,SRCLON,SRCALT,SRCFLG,SRCZEN(11),SRCSR(11)   SOURCE     2
      COMMON/TECTOR/  DETLAT,DETLON,DETALT,DETZEN,DETAZI(11)             TECTOR     2
      DATA  PI,RE / 3.141592653590,6.37103E+03 /                         RINOUT    73
CCC                                                                      RINOUT    74
C         UPON BEING CALLED FROM SUBROUTINE SURRAD INITIALLY WITH        RINOUT    75
C         IFIRE=0 (EVEN THOUGH IFIRES .GT. 0), RINOUT DECIDES WHETHER    RINOUT    76
C         THE SUN CAN BE A SOURCE, DEPENDING ON ITS ZENITH ANGLE.        RINOUT    77
CCC                                                                      RINOUT    78
      IF( IFIRE.GT.0 )  GO TO 20                                         RINOUT    79
      SINSIN = SIN(POSLAT)*SIN(SOLLAT)                                   RINOUT    80
      COSCOS = COS(POSLAT)*COS(SOLLAT)                                   RINOUT    81
      CSSOLZ = SINSIN + COSCOS*COS(POSLON-SOLLON)                        RINOUT    82
      IDAY = 0                                                           RINOUT    83
      IF( CSSOLZ.LT.0.0 )  GO TO 10                                      RINOUT    84
      IDAY = 1                                                           RINOUT    85
      SRCZEN(1) = ACOS( CSSOLZ )                                         RINOUT    86
   10 CONTINUE                                                           RINOUT    87
CC                                                                       RINOUT    88
CC        COMPUTE DETECTOR ZENITH ANGLE, DETZEN, AND, IF MAT .GT. 2 AND  RINOUT    89
CC        IDAY=1, THE DETECTOR AZIMUTH ANGLE FOR SUN, DETAZI(1).         RINOUT    90
CC        ALPHAD = EARTH-CENTRAL ANGLE BETWEEN RAYS TO DETECTOR AND      RINOUT    91
CC        LINE-OF-SIGHT INTERSECTION POINT                               RINOUT    92
      ALPHAD = CANGLE(DETLAT,DETLON,POSLAT,POSLON)                       RINOUT    93
      EPSD = (RE+POSALT)/(RE+DETALT)                                     RINOUT    94
      CD = (1.0-EPSD)/(1.0+EPSD)                                         RINOUT    95
      CD = 2.0*ATAN( CD/TAN(ALPHAD/2.))                                  RINOUT    96
      BETAD = 0.5*(PI-ALPHAD-CD)                                         RINOUT    97
      DETZEN = ALPHAD+BETAD                                              RINOUT    98
      IF( (IDAY.EQ.0) .OR. (MAT.LE.2) )  RETURN                          RINOUT    99
CC                                                                       RINOUT   100
CC         SET SUN INTO SOURCE COORDINATES.                              RINOUT   101
      SRCLAT = SOLLAT                                                    RINOUT   102
      SRCLON = SOLLON                                                    RINOUT   103
      GO TO 40                                                           RINOUT   104
   20 L=1                                                                RINOUT   105
CC                                                                       RINOUT   106
CC         SET FIREBALL-L INTO SOURCE COORDINATES.                       RINOUT   107
   30 SRCLAT = FBLAT(L)                                                  RINOUT   108
      SRCLON = FBLON(L)                                                  RINOUT   109
      SRCALT = FBALT(L)                                                  RINOUT   110
CC                                                                       RINOUT   111
      IF( MAT.LE.2 )  GO TO 60                                           RINOUT   112
CC                                                                       RINOUT   113
CC         START CALCULATION OF DETAZI(1) OR DETAZI(L+1),  (L=1,IFIRE)   RINOUT   114
```

```
   40 SINNP = COS( POSLAT )
      COSNP = SIN( POSLAT )
      COSNS = SIN( SRCLAT )
      SINNS = COS( SRCLAT )
      TWOPI = PI+PI
      PNS = ABS( SRCLON-POSLON )
      IF( PNS.GE.PI )  PNS = TWOPI-PNS
      SINPNS = SIN( PNS )
      PS = CANGLE(POSLAT,POSLON,SRCLAT,SRCLON)
      SINQSN = SINNP*SINPNS/SIN( PS )
CC         SOME NUMERICAL PRECAUTIONS ARE NECESSARY.
      ABSQSN = ABS( SINQSN )
      ABSONE = ABSQSN-1.0
      IF( (ABSQSN.GT.1.0) .AND. (ABSONE.LE.1.0E-10) )
     *   SINQSN = SIGN( 1.0,SINQSN )
      QSN = ASIN( SINQSN )
      COSNPR = COSNS*COS( PS )
      IF( COSNP.LT.COSNPR )  QSN = PI-QSN
      COSQSN = COS( QSN )
      QNS = ABS( SRCLON-DETLON )
      IF( QNS.GE.PI )  QNS = TWOPI-QNS
      COSQNS = COS( QNS )
      SINQNS = SIN( QNS )
      RNQS = ACOS( SINQNS*SINQSN*COSNS - COSQNS*COSQSN )
      SINNQS = SIN( RNQS )
      QN = ASIN( SINQSN*SINNS/SINNQS )
      CSQSNR = -COSQNS*COS( RNQS )
      IF( COSQSN.LT.CSQSNR )  QN = PI-QN
      SINAQ = COS( QN+DETLAT )
      PSI    = ASIN( SINAQ*SINNQS/SIN( ALPHAD ) )
      COSAQ = SIN( QN+DETLAT )
      QNP = ABS( DETLON-POSLON )
      IF( QNP.GE.PI )  QNP = TWOPI-QNP
      SINQNP = SIN( QNP )
      SINQP = SINQNP*SINNP/SINNQS
      SNQPSQ = SINQP*SINQP
      COSQP = SQRT( 1.0-SNQPSQ )
      COSAQR = ALPHAD*COSQP
      IF( COSAQ.LT.COSAQR )  PSI = PI-PSI
      IF( IFIRE.GT.0 )  GO TO 50
      DETAZI(1) = PSI
      RETURN
CC
CC---------------------------------------------------------------------
CC         THE REMAINING PORTION OF THIS SUBROUTINE IS NOT USED IN THE
CC         NBR MODULE.
   50 CONTINUE
CC         SET DETAZI(L+1).
      DETAZI(L+1) = PSI
CC
CC         COMPUTE SRCZEN(L+1) AND SRCSR(L+1).
CC         ALPHAF = EARTH-CENTRAL ANGLE BETWEEN RAYS TO FIREBALL AND
CC         LINE-OF-SIGHT INTERSECTION POINT
   60 ALPHAF = CANGLE( POSLAT,POSLON,SRCLAT,SRCLON )
      EPSF = (RE+POSALT)/(RE+SRCALT)
      CF = (1.0-EPSF)/(1.0+EPSF)
      CF = 2.*ATAN( CF/TAN(ALPHAF/2.) )
      BETAF = 0.5*(PI-ALPHAF-CF)
      SRCZEN(L+1) = ALPHAF+BETAF
      SRCSR(L+1) = RE*SIN(ALPHAF)/SIN(BETAF)
      IF( L.GE.IFIRE )  RETURN
      L = L+1
      GO TO 30
      END
```

```
      SUBROUTINE SEGMENT ( NSPEC, X1, NS1, P1, T1, X2, NS2, P2, T2,
     1                    DU, DUP )
C
C        *SEGMNT* DEVELOPES THE ABSORBER AND PARTIAL PRESSURE
C        INTEGRALS FOR SPECIES IN THE PATH ELEMENT FROM POINT 1
C        TO POINT 2.  ALL PROPERTIES, TEMPERATURE, PRESSURE, AND
C        CONCENTRATIONS, ARE ASSUMED TO VARY LINEARLY THROUGH THE
C        PATH ELEMENT.
C
CLJ   INPUT PARAMETERS
CLJ      ARGUMENT LIST
CLJ           NSPEC = NUMBER OF SPECIES (10, SET IN CALL FROM PATH).
CLJ                   THESE SPECIES ARE IDENTIFIED BY COMMENTS IN
CLJ                   SUBROUTINE SHELLS.
CLJ              X1 = DISTANCE ALONG LINE SEGMENT (0., SET IN CALL
CLJ                   FROM PATH), CM
CLJ             NS1 = XNS1(10)-ARRAY, SET IN CALL FROM PATH.
CLJ                 = ARRAY OF SPECIES CONCENTRATIONS AT START OF
CLJ                   LINE SEGMENT, 1/CM**3
CLJ              P1 = PSL1, SET IN CALL FROM PATH.
CLJ                 = PRESSURE AT START OF LINE SEGMENT, ATM
CLJ              T1 = TSL1, SET IN CALL FROM PATH.
CLJ                 = TEMPERATURE AT START OF LINE SEGMENT, DE  K
CLJ              X2 = DS, SET IN CALL FROM PATH.
CLJ                 = LENGTH OF LINE SEGMENT, CM
CLJ             NS2 = XNS2(10)-ARRAY, SET IN CALL FROM PATH.
CLJ                 = ARRAY OF SPECIES CONCENTRATIONS AT  END  OF
CLJ                   LINE SEGMENT, 1/CM**3
CLJ              P2 = PSL2, SET IN CALL FROM PATH.
CLJ                 = PRESSURE AT  END  OF LINE SEGMENT, ATM
CLJ              T2 = TSL2, SET IN CALL FROM PATH.
CLJ                 = TEMPERATURE AT  END  OF LINE SEGMENT, DEG K
CLJ      XY COMMON
CLJ           TT(I) = TEMPERATURE ARRAY IN ATMOSPHERIC TRANSMISSION
CLJ                   MODEL, SET AS DATA IN THE DRIVER PROGRAM.  (DEG K)
CLJ   OUTPUT PARAMETERS
CLJ      ARGUMENT LIST
CLJ       DU(10,10),= ARRAYS OF PATH INTEGRALS U(ATM CM) AND UP(ATM**2
CLJ      DUP(10,10)   CM) AT 10 TEMPERATURES FOR EACH OF 10 SPECIES.
CLJ                   THE UNITS ARE THOSE OF STEPHENS.  SAI/LJ PREFERS
CLJ                   UNITS OF CM AT STP FOR U AND ATM-CM AT STP FOR UP.
      COMMON / XY / TT(10)
      DIMENSION NS1(NSPEC), NS2(NSPEC), DU(10,NSPEC), DUP(10,NSPEC),
     1          XT(10), DNSDX(20), XNSO(20)
C
      REAL NS1, NS2, NL
      LOGICAL NGRAD
C
CLJ
CLJ        NL = LOSCHMIDT'S NUMBER, MOLECULES/CM**3 AT STP.  (STEPHENS
CLJ             PREFERS 1/(ATM CM**3) WITH STANDARD TEMPERATURE
CLJ             UNDERSTOOD.)
CLJ
      DATA NL / 2.687E19
C
      CALL XMIT ( -10*NSPEC, 0 , DU )
      CALL XMIT ( -10*NSPEC, 0., DUP )
```

```
      DPRDX = ( P2 - P1 ) / ( X2 - X1 )
      XPRO = P1 - X1 * DPRDX
      DO 1 M=1,NSPEC
      DNSDX(M) = ( NS2(M) - NS1(M) ) / ( ( X2 - X1 ) * NL )
      XNSO(M) = NS1(M) / NL - X1 * DNSDX(M)
    1 CONTINUE
C
      IF ( ABS( T2/T1-1. ) .GT. .005 ) GO TO 7
C
C         NEARLY ISOTHERMAL PATH ELEMENT
      TBAR = .5 * ( T1 + T2 )
      IT = 0
      DO 2 I=1,10
      IF ( TBAR .LE. TT(I) ) GO TO 3
      IT = I
    2 CONTINUE
C
    3 IF ( IT .EQ. 0  .OR.  IT .EQ. 10 ) GO TO 5
C
C         TEMPERATURE INSIDE TABLE RANGE
      FN = ( TBAR - TT(IT) ) / ( TT(IT+1) - TT(IT) )
      FF = 1. - FN
      DX1 = X2 - X1
      DX2 = X2**2 - X1**2
      DX3 = X2**3 - X1**3
      DO 4 M=1,NSPEC
      IF ( NS1(M) + NS2(M) .EQ. 0. ) GO TO 4
      TERM = DNSDX(M) * DX2 / 2. + XNSO(M) * DX1
      DU(IT,M) = FF * TERM
      DU(IT+1,M) = FN * TERM
      TERM = DNSDX(M) * DPRDX * DX3 / 3. + ( XPRO * DNSDX(M) +
     1       XNSO(M) * DPRDX ) * DX2 / 2. + XNSO(M) * XPRO * DX1
      DUP(IT,M) = FF * TERM
      DUP(IT+1,M) = FN * TERM
    4 CONTINUE
      RETURN
C
C         TEMPERATURE OUTSIDE TABLE RANGE
    5 IF ( IT .EQ. 0 ) IT = 1
      DX1 = X2 - X1
      DX2 = X2**2 - X1**2
      DX3 = X2**3 - X1**3
      DO 6 M=1,NSPEC
      IF ( NS1(M) + NS2(M) .EQ. 0. ) GO TO 6
      DU(IT,M) = DNSDX(M) * DX2 / 2. + XNSO(M) * DX1
      DUP(IT,M) = DNSDX(M) * DPRDX * DX3 / 3. + ( XPRO * DNSDX(M) +
     1           XNSO(M) * DPRDX ) * DX2 / 2. + XNSO(M) * XPRO * DX1
    6 CONTINUE
      RETURN
C
C         NON-ZERO TEMPERATURE GRADIENT
    7 NGRAD = T2 .LT. T1
      DO 8 I=1,10
      XT(I) = ( T2 - TT(I) ) / ( T2 - T1 ) * X1 +
     1        ( T1 - TT(I) ) / ( T1 - T2 ) * X2
    8 CONTINUE
      IT = 0
```

```
      IF ( NGRAD ) IT = 10
      II = 1
      DO 15 I=1,10
      IP = II
      II = I
      IF ( NGRAD ) II = 11 - I
      IF ( I .EQ. 1  .AND.  XT(II) .GE. X2 ) GO TO 5
      IF ( XT(II) .LE. X1  .OR.  XT(IP) .GE. X2 ) GO TO 15
      IF ( I .GT. 1 ) GO TO 11
C
C         FIRST PART OF PATH OUTSIDE TEMPERATURE TABLE RANGE
      DX1 = XT(II) - X1
      DX2 = XT(II)**2 - X1**2
      DX3 = XT(II)**3 - X1**3
    9 DO 10 M=1,NSPEC
      IF ( NS1(M) + NS2(M) .EQ. 0. ) GO TO 10
      DU(II,M) = DU(II,M) + DNSDX(M) * DX2 / 2. + XNSO(M) * DX1
      DUP(II,M) = DUP(II,M) + DNSDX(M) * DPRDX * DX3 / 3. + ( XPRO *
     1             DNSDX(M) + XNSO(M) * DPRDX ) * DX2 / 2. +
     2             XNSO(M) * XPRO * DX1
   10 CONTINUE
      GO TO 15
C
C         TEMPERATURE INSIDE TABLE RANGE
   11 XN = AMAX1( XT(IP), X1 )
      XF = AMIN1( XT(II), X2 )
      DX1 = XF - XN
      DX2 = XF**2 - XN**2
      DX3 = XF**3 - XN**3
      DX4 = XF**4 - XN**4
C
C         NEAR SIDE INTEGRAL TO NEXT POINT
      DXT = XT(II) - XT(IP)
      FF = ( XF - XT(IP) ) / DXT
      FN = ( XN - XT(IP) ) / DXT
      IT = II
C
C         INTEGRATE BY PARTS--DIFERENTIATING THE WEIGHTING FACTOR
   12 DO 13 M=1,NSPEC
      IF ( NS1(M) + NS2(M) .EQ. 0. ) GO TO 13
      DNN = 0.
      IF ( FF .NE. 0. ) DNN = ( DNSDX(M)*XF**2/2. + XNSO(M)*XF ) * FF
      IF ( FN .NE. 0. ) DNN = DNN - ( DNSDX(M) * XN**2 / 2. +
     1                        XNSO(M) * XN ) * FN
      DU(IT,M) = DU(IT,M) + DNN - ( DNSDX(M) * DX3 / 6. +
     1             XNSO(M) * DX2 / 2. ) / DXT
      DNNPP = 0.
      IF ( FF .NE. 0. ) DNNPP = ( DNSDX(M) * DPRDX * XF**3 / 3. +
     1                          ( XPRO * DNSDX(M) + XNSO(M) * DPRDX ) *
     2                          XF**2 / 2. + XNSO(M) * XPRO * XF ) * FF
      IF ( FN .NE. 0. ) DNNPP = DNNPP - ( DNSDX(M) * DPRDX * XN**3 / 3.
     1                          + ( XPRO * DNSDX(M) + XNSO(M) * DPRDX )*
     2                          XN**2 / 2. + XNSO(M) * XPRO * XN ) * FN
      DUP(IT,M) = DUP(IT,M) + DNNPP - ( DNSDX(M) * DPRDX * DX4 / 12. +
     1             ( XPRO * DNSDX(M) + XNSO(M) * DPRDX ) * DX3 / 6. +
     2             XNSO(M) * XPRO * DX2 / 2. ) / DXT
   13 CONTINUE
```

```
      IF ( IT .NE. II ) GO TO 14
C
C          FAR SIDE INTEGRAL FROM PASSED POINT
      DXT = XT(IP) - XT(II)
      FF = ( XF - XT(II) ) / DXT
      FN = ( XN - XT(II) ) / DXT
      IT = IP
      GO TO 12
C
   14 IF ( I .LT. 10  .OR.  XT(II) .GE. X2 ) GO TO 15
C
C          LAST PART OF PATH OUTSIDE TEMPERATURE TABLE RANGE
      DX1 = X2 - XT(II)
      DX2 = X2**2 - XT(II)**2
      DX3 = X2**3 - XT(II)**3
      GO TO 9
C
   15 CONTINUE
C
      IF ( NGRAD ) IT = 10 - IT
      IF ( IT .EQ. 0  .OR.  IT .EQ. 10 ) GO TO 5
C
      RETURN
      END
```

```
      SUBROUTINE SETALT ( ALMIN, ALMAX, JBAND )                         SETALT
CCC                                                                     SETALT
C         SUBROUTINE SETALT, CALLED FROM THE DRIVER PROGRAM DRVUPW,     SETALT
C         DETERMINES THE ALTITUDES AT WHICH SUBROUTINE UPWELL COMPUTES  SETALT
C         THE UPWELLING NATURAL RADIATION.                              SETALT
C         A SET OF CHARACTERISTIC ALTITUDES HAS BEEN PREVIOUSLY SELECTED SETALT
C         FOR EACH OF THE 10 SPECTRAL BINS.  IF THE WAVELENGTH-BAND OF  SETALT
C         INTEREST (ALMIN,ALMAX) SPANS MORE THAN ONE BIN, WE USE A SET  SETALT
C         OF ALTITUDES OBTAINED BY COMBINING THOSE FOR EACH OF THE      SETALT
C         SPANNED BINS.                                                 SETALT
CCC                                                                     SETALT
C         INPUT PARAMETERS                                              SETALT
C            ARGUMENT LIST                                              SETALT
C               ALMIN, - MINIMUM AND MAXIMUM WAVELENGTHS FOR WHICH      SETALT
C               ALMAX    UPWELLING NATURAL RADIATION IS TO BE COMPUTED, SETALT
C                        MICRONS                                        SETALT
C                JBAND - BROAD-BAND LOOP INDEX (1,5)                    SETALT
C                                                                       SETALT
C         OUTPUT PARAMETERS                                             SETALT
C            COMMON UPWELS                                              SETALT
C              NALT(JBAND) - NUMBER OF ALTITUDES FOR BROAD-BAND INDEX   SETALT
C                            JBAND                                      SETALT
C              ZKM(I,JBAND) I=1,NALT(JBAND)                             SETALT
C                          - ALTITUDES OF POINT V ABOVE UPWALT AT WHICH SETALT
C                            UPWELLING RADIANCE IS COMPUTED FOR BROAD-  SETALT
C                            BAND INDEX JBAND, KM                       SETALT
CCC                                                                     SETALT
      COMMON/UPWELS/ UPWALT,UPWLON,UPWLAT,NALT(5),ZKM(13,5),NNADIR,NAZI, UPWELS
     *               NWAVE(5),IDAYV,CLDFLG,UPRADN(13,10,5),WV(10,5),IKM, UPWELS
     *               NBANDS                                              UPWELS
      COMMON/UPWELS1/                                                    UPWELS
     2                RO10(6,10),RO10A(6,10,10),RO10N(6,10),             UPWELS
     3                RO25(6,10),RO25A(6,10,10),RO25N(6,10),             UPWELS
     4                RO50(6,10),RO50A(6,10,10),RO50N(6,10),             UPWELS
     5                RO90(6,10),RO90A(6,10,10),RO90N(6,10),             UPWELS
     6                R100(6,10),R100A(6,10,10),R100N(6,10)              UPWELS
     7                          ,ARCVA(6,10,10),ARCVN(6,10)              UPWELS
      DIMENSION  HUPWEL(11,10),BINLAM(11),NALTL(10),ALT(56)              SETALT
C                                                                        SETALT
C         DEFINITIONS OF DATA...                                         SETALT
C               NBINL1 - NUMBER OF WAVELENGTH-BIN BOUNDARIES MINUS ONE   SETALT
C                      - NUMBER OF WAVELENGTH BINS                       SETALT
C            BINLAM(L)   L=1,(NBINL1+1)                                  SETALT
C                      - WAVELENGTH OF BIN BOUNDARY, MICRONS             SETALT
C             NALTL(M)   M=1,NBINL1                                      SETALT
C                      - NUMBER OF ALTITUDES FOR WAVELENGTH-BIN M        SETALT
C          HUPWEL(I,M)   I=1,NALTL(M)  M=1,NBINL1                        SETALT
C                      - ALTITUDE-I FOR WAVELENGTH-BIN M, KM             SETALT
C                                                                        SETALT
      DATA NBINL1 / 10 /                                                 SETALT
      DATA BINLAM / 2.000, 2.100, 2.575, 2.675, 2.725, 2.875, 4.150,     SETALT
     $              4.550, 4.750, 4.850, 5.000 /                         SETALT
      DATA NALTL  /       5,     4,     5,    11,     5,     4,     9,   SETALT
     $                    4,     5,     4        /                       SETALT
      DATA HUPWEL / 0., 1.,12.,20.,100.,0., 0., 0., 0., 0., 0.,         SETALT
     2              0., 1.,12.,100.,0., 0., 0., 0., 0., 0., 0.,         SETALT
     3              0., 1., 3.,12.,100.,0., 0., 0., 0., 0., 0.,         SETALT
```

```
     4                0., 1., 2., 4., 9.,12.,20.,30.,50.,70.,100.,
     5                0., 1., 3.,12.,100.,0., 0., 0., 0., 0., 0.,
     6                0., 1.,12.,100.,0., 0., 0., 0., 0., 0., 0.,
     7                0., 1., 3., 6.,12.,20.,50.,70.,100.,0., 0.,
     8                0., 1.,12.,100.,0., 0., 0., 0., 0., 0., 0.,
     9                0., 1.,12.,30.,100.,0., 0., 0., 0., 0., 0.,
     A                0., 1.,12.,100.,0., 0., 0., 0., 0., 0., 0./
C
C          DETERMINE WHICH WAVELENGTH BINS THE MINIMUM AND MAXIMUM
C          WAVELENGTHS, ALMIN AND ALMAX, FALL INTO.
      IF ( ALMIN .LT. 2.0 )  GO TO 15
      DO 10 K=1,NBINL1
      IF ( ALMIN .LT. BINLAM(K+1) )  GO TO 20
   10 CONTINUE
   15 WRITE(6,16)
   16 FORMAT(1H0,1X,64HA BOUNDARY WAVELENGTH IS OUTSIDE THE 2.0- TO 5.0-
     $MICRON INTERVAL)
      STOP 1
   20 MMIN = K
C          NOW HAVE INDEX MMIN OF WAVELENGTH BIN FOR MINIMUM WAVELENGTH.
      DO 25 K=1,NBINL1
      IF ( ALMAX .LE. BINLAM(K+1) )  GO TO 35
   25 CONTINUE
   30 WRITE(6,16)
      STOP 2
   35 MMAX = K
C          NOW HAVE INDEX MMAX OF WAVELENGTH BIN FOR MAXIMUM WAVELENGTH.
C
      IF ( MMAX .NE. MMIN )  GO TO 50
      NALTJ = NALTL(MMIN)
      NALT(JBAND) = NALTJ
      DO 40 I=1,NALTJ
      ZKM(I,JBAND) = HUPWEL(I,MMIN)
   40 CONTINUE
      GO TO 90
   50 CONTINUE
      J = 0
      DO 70 M=MMIN,MMAX
      NH = NALTL(M)
      DO 60 I=1,NH
      J = J + 1
      ALT(J) = HUPWEL(I,M)
   60 CONTINUE
   70 CONTINUE
      JMAX = J
C          SORT ALT ARRAY IN ORDER OF INCREASING ALTITUDES AND THEN
C          ELIMINATE REDUNDANT ALTITUDES.
      CALL SORTLJ(ALT,ALT,ALT,JMAX,0)
      JMM1 = JMAX - 1
      J = 1
      ZKM(1,JBAND) = ALT(1)
      DO 80 I=1,JMM1
      IF ( ALT(I+1) .EQ. ALT(I) )  GO TO 80
      J = J + 1
      ZKM(J,JBAND) = ALT(I+1)
   80 CONTINUE
      NALT(JBAND) = J
   90 CONTINUE
      END
```

```
      SUBROUTINE SHELLS
C
C        *SHELLS* PREPARES A TABLE OF PHYSICAL PROPERTIES FOR THE
C        AMBIENT ATMOSPHERE USED IN THE CALCULATION OF ATMOSPHERIC
C        TRANSMISSION.
C
CLJ
CLJ   INPUT PARAMETERS
CLJ      ATMOUP COMMON
CLJ              PP = PRESSURE, DYNES/CM**2
CLJ              TT = TEMPERATURE, DEG K
CLJ          SNI(I) = DENSITY OF SPECIES I, 1/CM**3
CLJ                   PARTICULAR SPECIES ARE INDICATED AS FOLLOWS...
CLJ                   N  I=IMAP(N)  SNI(I)
CLJ                   --  ---------  ------
CLJ                   1       8        NO
CLJ                   2      11        NO+
CLJ                   3      21        N2O
CLJ                   4      15        NO2
CLJ                   5      14        O3
CLJ                   6       6        CO2
CLJ                   7      20        CO
CLJ                   8      22        CH4
CLJ                   9      16        H2O
CLJ                  10      18        OH
CLJ      XYZCOM COMMON
CLJ            FACT = PATH INTEGRATION FACTOR CONTROLLING THE NUMBER OF
CLJ                   ALTITUDES AND SPACING (MAY HAVE A VALUE BETWEEN
CLJ                   0.1 AND 10, PER EWING.  NOMINAL VALUE IS 1.0)
CLJ       FOR FACT=1.0, WE HAVE NS=77 AND JCHNGE=40.
CLJ              J          HS, KM
CLJ             ***        ********
CLJ              1            0.0
CLJ              2            0.526
CLJ             39           20.000
CLJ             40           22.105
CLJ             58           60.0
CLJ             77          100.0
CLJ
CLJ       SUBSEQUENT TO THE INITIAL DEVELOPMENT OF SUBROUTINE SHELLS BY
CLJ       L. EWING OF GET, J. GARBARINO OF GRC SIGNIFICANTLY REVISED THE
CLJ       SETTING OF THE ATMOSPHERIC SHELLS WITH THE INTENT TO REDUCE
CLJ       THE RUNNING TIME.  FOR THE ORIGINAL SETTING OF THE ATMOSPHERIC
CLJ       SHELLS, THE MAXIMUM NUMBER OF BOUNDARIES WAS 81.  FOR THE GRC
CLJ       SETTING, IT IS 61.  THUS, SEVERAL VARIABLES COULD HAVE THEIR
CLJ       DIMENSIONS REDUCED TO 61 FROM 81.  GRC HAS ALSO MADE FACT
CLJ       DEPENDENT ON TRNSOPT IN PROGRAM ATKGEN BY SETTING FACT TO 1.0
CLJ       IF TRNSOPT .NE. FAST AND TO 10.0 IF TRNSOPT .EQ. FAST.
CLJ       WE HAVE KEPT FACT INDEPENDENT OF TRNSOPT.
CLJ
CLJ       WE RECORD THE BOUNDARIES FOR THREE VALUES OF FACT, PER GRC.
CLJ
CLJ       FOR FACT = 1,  X0=1.25,  X1=3.125, X2=7.8125
CLJ        J    HS             J       HS              J       HS
CLJ        -   ----      ---------   ------      ---------   -------
CLJ        1   0.        JCHNG1=10   13.125      JCHNG2=18   42.8125
CLJ        2   1.25             11   16.250             19   50.6250
```

```
CLJ      3   2.50             12   19.375             20   58.4375
CLJ      4   3.75             13   22.500             21   66.2500
CLJ      5   5.00             14   25.625             22   74.0625
CLJ      6   6.25             15   28.750             23   81.8750
CLJ      7   7.50             16   31.875             24   89.6875
CLJ      8   8.75             17   35.000             25   97.5000
CLJ      9  10.00
CLJ
CLJ      FOR FACT = 10, X0=3.0,    X1=7.5,    X2=18.75
CLJ      J    HS                   J     HS                    J      HS
CLJ      -    ----          --------    ------        ---------   ------
CLJ      1    0.0           JCHNG1=5    16.5          JCHNG2= 8    50.25
CLJ      2    3.0                  6    24.0                  9    69.00
CLJ      3    6.0                  7    31.5                 10    87.75
CLJ      4    9.0                                            11   106.50
CLJ
CLJ      FOR FACT = .1, X0=0.5,    X1=1.25,   X2=3.125
CLJ      J    HS                   J     HS                    J      HS
CLJ      -    ----          ---------   -----         ---------   ------
CLJ      1    0.0           JCHNG1=22   11.25         JCHNG2=42   38.125
CLJ      2    0.5                  23   12.50                43   41.250
CLJ      3    1.0                  24   13.75                44   44.375
CLJ      .                          .     .                   .     .
CLJ      .                          .     .                   .     .
CLJ      .                          .     .                   .     .
CLJ     21   10.0                  41   35.00                61   97.500
CLJ
CLJ   OUTPUT PARAMETERS
CLJ      XYZCOM COMMON
CLJ               NS = NUMBER OF ALTITUDE BOUNDARIES
CLJ        HSHELL(J) = ALTITUDE BOUNDARIES, CM (J=1,NS)
CLJ            TS(J) = TEMPERATURE AT ALTITUDE BOUNDARY J, DEG K (J=1,NS)
CLJ            PS(J) = PRESSURE AT ALTITUDE BOUNDARY J, ATM  (J=1,NS)
CLJ     XNSPEC(J,N) = SPECIES-N DENSITY AT ALTITUDE BOUNDARY J, 1/CM**3
CLJ                   (J=1,NS , N=1,10)
CLJ
      DIMENSION PRWATR(81)
      DIMENSION IMAP(10)
      COMMON / ATMOUP / HL, SBAR, IDORN, PP, RHO, TT, SNI(30), HRHO,
     1                  FEHSEO
      COMMON / XYZCOM / ITMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81),
     1                 XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS,
     2                 FACT
C
      DATA IMAP / 8, 11, 21, 15, 14, 6, 20, 22, 16, 18 /
C
CLJ       THE ORIGINAL GET ALGORITHM IS COMMENTED OUT WITH CGET.
CGET      NS = 40.5 - 2.5 * FACT
CGET      NS = MAX0( 30, MIN0( 2 * NS, 80 ) ) +1
CGET      JCHNGE = 2 + NS / 2
CGET      X = 40. / FLOAT( NS - 1 )
CLJ
      NS = 5.1 + 7./FACT
      NS = MAX0( 10, MIN0( 60, 2*NS ) ) + 1
      JCHNG1 = 2 + NS/3
      JCHNG2 = 2 + 2*NS/3
      X = 30./FLOAT(NS-1)
```

```
      HS = -X
      WRITE(6,5)
    5 FORMAT(1H1,44X,43H* * *  OUTPUT FROM SUBROUTINE SHELLS  * * *,//,1
     $H ,126H  J    HSHELL      TS        PS         NO        NO+       N2O
     $      NO2         O3         CO2         CO         CH4        H2O         O
     $H/,1H ,28H           K'      DEG K    ATMOS ,10(3X,7H1/CM**3))
      DO 10 J=1,NS
CGET      IF( J .EQ. JCHNGE )  X = 4. * X
      IF( J .EQ. JCHNG1 )  X = 2.5*X
      IF( J .EQ. JCHNG2 )  X = 2.5*X
      HS = HS + X
C         ESTABLISH ARRAY OF SHELL-BOUNDARY ALTITUDES.
      HSHELL(J) = HS * 1.E5
      CALL ATMOSU ( 2, HS )
      CALL SPCMIN ( 2, HS )
      SNI(11) = 0.
CLJ
CLJ       THE TEST ALTITUDE IN THE FOLLOWING IF-STATEMENT, INITIALLY SET
CLJ       TO 75 KM BY G.E.TEMPO, HAS BEEN CHANGED TO 90 KM BECAUSE
CLJ       SUBROUTINE IONOSU COMPUTES NO+ ONLY FOR ALTITUDES .GE. 90 KM.
CLJ       FURTHER, NO+ IS PROBABLY NEGLIBLE BELOW 90 KM.
CLJ
      IF( HS.GE.90. )  CALL IONOSU( 2,HS )
      TS(J) = AMIN1( 300.,TT )
      PS(J) = PP / 1.01325E6
      DO 1 N=1,10
      I = IMAP(N)
      XNSPEC(J,N) = SNI(I)
    1 CONTINUE
      WRITE(6,11)  J,HS,TS(J),PS(J),(XNSPEC(J,N),N=1,10)
   11 FORMAT (1X,I3,1PE10.3,0PF6.1,1P11E10.3)
   10 CONTINUE
CLJ       TO FACILITATE COMPARING OUR ATMOSPHERE WITH THOSE USED BY
CLJ       OTHER WORKERS, THE FOLLOWING STATEMENTS (DO-LOOP-20 AND
CLJ       ASSOCIATED PRINT) WERE ADDED TO COMPUTE THE WATER CONTENT
CLJ       OF THE ATMOSPHERE ALONG A VERTICAL PATH ABOVE EACH OF THE
CLJ       SHELL BOUNDARIES.  THE WATER CONTENT ABOVE BOUNDARY J,
CLJ       PRWATR(J), IS EXPRESSED IN UNITS OF PRECIPITABLE CENTIMETERS,
CLJ       I.E.,
CLJ                 PR CM(H2O) = 3.34*E+22 MOLECULES/CM**2 .
CLJ       WE ASSUME AN EXPONENTIAL DEPENDENCE OF THE WATER VAPOR
CLJ       CONCENTRATION BETWEEN THE BOUNDARIES AND HENCE CALL FUNCTION
CLJ       ACCUM WITH ITYPE = 2.
      PRWATR(NS) = 0.
      DO 20 I=2,NS
      J = NS - I + 1
      DELPRW = ACCUM( 2, HSHELL(J), HSHELL(J+1), XNSPEC(J,9),
     $                XNSPEC(J+1,9), HSHELL(J), HSHELL(J+1) )/3.34E+22
      PRWATR(J) = PRWATR(J+1) + DELPRW
   20 CONTINUE
      WRITE(6,25)  ( HSHELL(J), PRWATR(J), J=1,NS )
   25 FORMAT (*0  HSHELL(KM), PRWATR(PR CM) =*/(5X,1P10E12.4))
      RETURN
      END
```

```
      SUBROUTINE SOLRAD(K,B,E)                                          SOLRAD
CCC                                                                     SOLRAD
C         SUBROUTINE SOLRAD PROVIDES THE SOLAR SPECTRAL IRRADIANCE      SOLRAD
C         AT THE TOP OF THE EARTH'S ATMOSPHERE, IN THE SPECTRAL RANGE   SOLRAD
C         FROM 2 TO 5 MICROMETERS (OR 5000 TO 2000 WAVENUMBERS).        SOLRAD
C         THE NASA DATA ADOPTED BY THE ASTM HAVE BEEN FITTED BY         SOLRAD
C         PIECEWISE-CONTINUOUS POWER-LAW EXPRESSIONS.                   SOLRAD
CCC                                                                     SOLRAD
C     INPUT PARAMETERS                                                  SOLRAD
C              B - WAVENUMBER (CM-1) ,  K=1,2,3,4                       SOLRAD
C                - WAVELENGTH (UM)   ,  K=5,6,7,8                       SOLRAD
C              K - INDEX SPECIFYING UNITS FOR INPUT AND OUTPUT          SOLRAD
CCC                                                                     SOLRAD
C     OUTPUT PARAMETERS                                                 SOLRAD
C              E - SOLAR SPECTRAL IRRADIANCE AT THE TOP OF THE EARTH'S  SOLRAD
C                  ATMOSPHERE, IN UNITS OF...                           SOLRAD
C                        PHOTONS/(CM**2 SEC CM-1) ,  K=1,5              SOLRAD
C                        PHOTONS/(CM**2 SEC UM)   ,  K=2,6              SOLRAD
C                        WATTS/(CM**2 CM-1)       ,  K=3,7              SOLRAD
C                        WATTS/( M**2 UM )        ,  K=4,8              SOLRAD
CCC                                                                     SOLRAD
      DATA  C,H / 2.997925E+10, 6.626176E-27 /                          SOLRAD
      DATA  E2P2,E2P9,E3P5,E4P0,E5P0 / 79.0,35.0,14.6,9.50,3.79 /       SOLRAD
      DATA  C2P2,C2P9,C3P5,C4P0,C5P0 / 2.2,2.9,3.5,4.0,5.0 /            SOLRAD
      DATA  FLAG / -2.0 /                                               SOLRAD
CCC                                                                     SOLRAD
      IF( FLAG.GT.0.0 )  GO TO 20                                       SOLRAD
      FLAG = +2.0                                                       SOLRAD
      HCIV = 1.0E+07/(H*C)                                              SOLRAD
      A2P2 = ALOG(E2P9/E2P2)/ALOG(C2P9/C2P2)                            SOLRAD
      A2P9 = ALOG(E3P5/E2P9)/ALOG(C3P5/C2P9)                            SOLRAD
      A3P5 = ALOG(E4P0/E3P5)/ALOG(C4P0/C3P5)                            SOLRAD
      A4P0 = ALOG(E5P0/E4P0)/ALOG(C5P0/C4P0)                            SOLRAD
   20 CONTINUE                                                          SOLRAD
      A = B                                                             SOLRAD
      IF( A.LE.0.0 )  GO TO 27                                          SOLRAD
      IF( (K.LE.0) .OR. (K.GT.8) )  GO TO 29                            SOLRAD
      IF( K.LT.5 )  A = 1.0E+04/A                                       SOLRAD
      IF( (A.LT.2.) .OR. (A.GT.5.) )  GO TO 27                          SOLRAD
      IF( A.GE.C4P0 )  GO TO 23                                         SOLRAD
      IF( A.GE.C3P5 )  GO TO 22                                         SOLRAD
      IF( A.GE.C2P9 )  GO TO 21                                         SOLRAD
      E = E2P2*(A/C2P2)**A2P2                                           SOLRAD
      GO TO 24                                                          SOLRAD
   21 E = E2P9*(A/C2P9)**A2P9                                           SOLRAD
      GO TO 24                                                          SOLRAD
   22 E = E3P5*(A/C3P5)**A3P5                                           SOLRAD
      GO TO 24                                                          SOLRAD
   23 E = E4P0*(A/C4P0)**A4P0                                           SOLRAD
   24 IF( (K.EQ.4) .OR. (K.EQ.8) )  GO TO 28                            SOLRAD
      IF( (K.EQ.3) .OR. (K.EQ.7) )  GO TO 26                            SOLRAD
      IF( (K.EQ.2) .OR. (K.EQ.6) )  GO TO 25                            SOLRAD
      E = 1.0E-12*HCIV*E*A*A*A                                          SOLRAD
      GO TO 28                                                          SOLRAD
   25 E = 1.0E-08*HCIV*E*A                                              SOLRAD
      GO TO 28                                                          SOLRAD
   26 E = 1.0E-08*E*A*A                                                 SOLRAD
```

```
   28 RETURN
   27 PRINT 31,  A
   31 FORMAT (82H0 SUBROUTINE SOLRAD HAS BEEN CALLED WITH WAVELENGTH (OR
     $ WAVENUMBER) OUT OF RANGE. ,E12.4)
      CALL EXIT
   29 PRINT 33,  K
   33 FORMAT (68H0 SUBROUTINE SOLRAD HAS BEEN CALLED WITH IMPROPER VALUE
     $ FOR INDEX K.,I10)
      CALL EXIT
      END
```

```
      SUBROUTINE SORTLJ( A,B,C,N,LOHI )
CCC
C          GIVEN THE A ARRAY OF LENGTH N, THIS ROUTINE SORTS THE
C          ARRAY FROM LOW TO HIGH IF LOHI.LE.0 AND FROM HIGH TO LOW
C          IF LOHI.GT.0  .
C          THE B AND C ARRAYS ARE SIMPLY CARRIED ALONG.
CCC
      DIMENSION  A(1), B(1), C(1)
CCC
      M = N
   20 M = M/2
      IF( M.EQ.0 ) GO TO 40
      K = N-M
      J = 1
   41 I = J
   49 L = I+M
      IF( LOHI )  50,50,52
C
C * * * SORT LOW TO HIGH.
   50 IF( A(L).GE.A(I) ) GO TO 60
      GO TO 55
C
C * * * SORT HIGH TO LOW.
   52 IF( A(L).LE.A(I) ) GO TO 60
   55 X = A(I)
      Y = B(I)
      Z = C(I)
      A(I) = A(L)
      B(I) = B(L)
      C(I) = C(L)
      A(L) = X
      B(L) = Y
      C(L) = Z
      I = I-M
      IF( I.GE.1 ) GO TO 49
   60 J = J+1
      IF( J-K ) 41,41,20
   40 RETURN
      END
```

```
      SUBROUTINE STEP ( RX, SHAT, DIST, NC, DS, XFRACS, INDX )
C
C        *STEP* CALCULATES THE INTERSECTIONS OF AN OPTICAL PATH WITH
C        THE LINEARLY VARYING SHELLS IN THE ATMOSPHERIC MODEL.  PATH
C        ELEMENTS LESS THAN TEN METERS IN LENGTH ARE ASSIGNED
C        TO THE NEIGHBORING SHELL.
C
CLJ
CLJ   INPUT PARAMETERS
CLJ      ARGUMENT LIST
CLJ           RX(I) = LOCATION VECTOR TO ONE END OF TRANSMISSION PATH,
CLJ                   TYPICALLY BUT NOT NECESSARILY AT THE DETECTOR, CM
CLJ         SHAT(I) = UNIT VECTOR ALONG THE TRANSMISSION PATH FROM RY TO
CLJ                   RX,  CM
CLJ                     (FOR RX AND SHAT  I=1,3)
CLJ            DIST = MAGNITUDE OF DISTANCE ALONG TRANSMISSION PATH
CLJ                   FROM RY TO RX, CM
CLJ              NC = INITIALIZATION VALUE.  NORMALLY SET TO 0 AND LEADS
CLJ                   TO DS(1) BEING SET TO 0.0.
CLJ      XYZCOM COMMON
CLJ              NS = NUMBER OF SHELL BOUNDARIES IN ATMOSPHERIC
CLJ                   TRANSMISSION MODEL
CLJ   OUTPUT PARAMETERS
CLJ      ARGUMENT LIST
CLJ              NC = NUMBER OF PATH SEGMENTS PLUS ONE ON THE
CLJ                   TRANSMISSION PATH FROM RY TO RX, OR EQUIVALENTLY,
CLJ                   THE NUMBER OF ENDPOINTS.
CLJ                 FOR  I=1,NC
CLJ         DS(I+1) = LENGTH OF LINE SEGMENT I ALONG TRANSMISSION
CLJ                   PATH, CM
CLJ                   NOTE...  IT IS ALWAYS TRUE THAT DS(1)=0. AND
CLJ                   DS(NC+1)=-1. (THERE ARE TWO MORE VALUES OF DS
CLJ                   THAN THERE ARE SEGMENTS.)
CLJ       XFRACS(I) - (SEE NOTE IN SUBROUTINE ATMRAD)
CLJ         INDX(I) = INDEX OF SHELL BOUNDARY AT OR JUST BEFORE THE
CLJ                   START OF THE LINE SEGMENT I.  INDX(NC) WILL BE THE
CLJ                   INDEX OF THE SHELL BOUNDARY JUST AFTER THE LAST
CLJ                   ENDPOINT.
CLJ                   NOTE...  INDX(NC+1) = 0
CLJ
      DIMENSION DS(100), XFRACS(100), INDX(100), RX(3), SHAT(3)
      COMMON / XYZCOM / IDMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81),
     1                 XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS,
     2                 FACT
      DATA  ERAD / 6.37103E+08 /
C     ERAD = RBODY            WHEN /CONCON/ IS ADDED
C
C         DETERMINE INITIAL DIRECTION OF INTEGRATION
      RXKDOT = DOT( RX, SHAT )
      IF ( RXKDOT ) 2, 2, 1
    1 SIGN = 1.
      IS = 1
      GO TO 3
    2 SIGN = -1.
      IS = -1
C         INITIALIZE COUNTERS AND OTHER VALUES
    3 RX2 = DOT( RX, RX )
```

```
      RXL = SQRT( RX2 )
      RKD2 = RXKDOT**2
      IF ( NC .EQ. 0 ) DS(1) = 0.
      IF ( NC .GT. 0 ) NC = NC - 1
      DOLD = 0.
      SRAD = RXL
      NST = 0
      IF ( IS .LT. 0 ) NST = NS + 1
      N = NST
C         SAVE PREVIOUS SHELL INDEX
    4 NOLD = N
C         STEP TO NEXT SHELL
      N = N + IS
C         TEST FOR ATMOSPHERE LIMIT
      IF ( N .EQ. 0  .OR.  N .GT. NS ) GO TO 7
C         UPDATE SHELL RADIUS
      SROLD = SRAD
      SRAD = ERAD + HSHELL(N)
      IF ( SRAD .NE. SROLD ) XFRAC = FRAC( SRAD, SROLD, SRAD, RXL )
      DISC = RKD2 - ( RX2 - SRAD**2 )
C         NEGATIVE DISCRIMINANT IMPLIES NO INTERSECTION
      IF ( DISC ) 8, 5, 5
    5 DNEW = AMAX1( SIGN*SQRT( DISC ) - RXKDOT, 0. )
      DELTA = DNEW - DOLD
      IF ( DELTA - 1.E3 ) 4, 4, 6
C         UPDATE DISTANCE AND STORE INTEGRATION CELL INFORMATION
    6 DOLD = DNEW
      NC = NC + 1
      XFRACS(NC) = XFRAC
      INDX(NC) = NOLD
C         IGNORE STEP TO TOP OF ATMOSPHERE
      IF ( NOLD .GT. NS ) NC = NC - 1
      DS(NC+1) = DELTA
C         TEST DISTANCE LIMIT
      IF ( DIST .GE. DNEW+1.E3 )   IF ( NC - 99 ) 4, 10, 10
      DS(NC+1) = DS(NC+1) - ( DNEW - DIST )
C         LAST CELL ON PATH
    7 RXL = SQRT( RX2 + DIST**2 + 2. * RXKDOT * DIST )
      IF ( N .EQ. 0 ) RXL = ERAD
      NC = NC + 1
      INDX(NC) = INDX(NC-1) + IS
      DS(NC+1) = -1.
      XFRACS(NC) = FRAC( SRAD, SROLD, RXL, SROLD )
      INDX(NC+1) = 0
      RETURN
C         IF INTEGRATION HAS BEEN DOWN, SWITCH TO UP
    8 IF ( SIGN ) 9, 4, 4
    9 SIGN = 1.
      IS = 1
C         SET MIDPOINT OF CHORD AS AN INTEGRATION POINT (END OF CELL)
      RXL = SQRT( RX2 - RKD2 )
      DNEW = -RXKDOT
      DELTA = DNEW - DOLD
      IF ( DELTA - 1.E3 ) 4, 4, 6
C         DIMENSION LIMIT HAS BEEN EXCEEDED
   10 INDX(99) = INDX(99) + IS
      XFRACS(99) = 1.
      NC = 99
      DS(100) = -1.
      INDX(100) = 0
      RETURN
      END
```

```
      SUBROUTINE STEPS ( RX, RY, NC, DS, XFRACS, INDX )                  STEPS
C                                                                        STEPS
C        *STEPS* IS AN ENTRY TO *STEP* WHEN THE PATH IS DEFINED BY       STEPS
C        ITS END POINTS.                                                 STEPS
C                                                                        STEPS
CLJ                                                                      STEPS
CLJ   INPUT PARAMETERS                                                   STEPS
CLJ      ARGUMENT LIST                                                   STEPS
CLJ           RX(I) = LOCATION VECTOR TO ONE END OF TRANSMISSION PATH,   STEPS
CLJ                   TYPICALLY BUT NOT NECESSARILY AT THE DETECTOR, CM  STEPS
CLJ           RY(I) = LOCATION VECTOR TO ONE END OF TRANSMISSION PATH,   STEPS
CLJ                   TYPICALLY AT THE SCATTERING OR SOURCE POINT, CM    STEPS
CLJ                     (FOR RX AND RY  I=1,3)                           STEPS
CLJ              NC = INITIALIZATION VALUE.  NORMALLY SET TO 0 AND LEADS STEPS
CLJ                   TO DS(1) BEING SET TO 0.0 IN SUBROUTINE STEP.      STEPS
CLJ   OUTPUT PARAMETERS                                                  STEPS
CLJ      INTERNAL USE (FOR CALL TO SUBROUTINE STEP)                      STEPS
CLJ         SHAT(I) = UNIT VECTOR ALONG TRANSMISSION PATH FROM RY TO RX, STEPS
CLJ                    CM  (I=1,3)                                       STEPS
CLJ            DIST = MAGNITUDE OF DISTANCE ALONG TRANSMISSION PATH FROM STEPS
CLJ                   RY TO RX,  CM                                      STEPS
CLJ      ARGUMENT LIST                                                   STEPS
CLJ        (FOLLOWING QUANTITIES ARE OBTAINED BY A CALL TO STEP)         STEPS
CLJ       NC, DS, XFRACS, AND INDX.     (SEE *STEP* FOR DEFINITIONS)     STEPS
CLJ                                                                      STEPS
      DIMENSION DS(100), XFRACS(100), INDX(100), SHAT(3), RX(3), RY(3)   STEPS
C                                                                        STEPS
C        PATH SEGMENTS LESS THAN 10 METERS IN LENGTH ARE NOT TREATED AS  STEPS
C        SEPARATE INTEGRATION STEPS.                                     STEPS
C                                                                        STEPS
CLJ                                                                      STEPS
CLJ            SHAT = VECTOR DIFFERENCE BETWEEN VECTORS RY AND RX        STEPS
CLJ            DIST = MAGNITUDE OF VECTOR SHAT                           STEPS
CLJ                                                                      STEPS
      CALL SUBVEC ( RY, RX, SHAT )                                       STEPS
      DIST = SQRT( DOT( SHAT, SHAT ))                                    STEPS
      IF ( DIST .LT. 1.E3 ) RETURN                                       STEPS
CLJ                                                                      STEPS
CLJ       OBTAIN A UNIT VECTOR ALONG THE VECTOR SHAT AND CALL IT SHAT    STEPS
CLJ                                                                      STEPS
      CALL UNITY ( SHAT, SHAT )                                          STEPS
      CALL STEP ( RX, SHAT, DIST, NC, DS, XFRACS, INDX )                 STEPS
      RETURN                                                             STEPS
      END                                                                STEPS
```

```
      SUBROUTINE SUBVEC ( VX, VY, DVXY )                                 SUBVEC
CLJ                                                                      SUBVEC
CLJ       SUBROUTINE SUBVEC RETURNS THE DIFFERENCE BETWEEN VECTORS VX    SUBVEC
CLJ      AND VY, I.E.,  DVXY(1-3) = VX(1-3) - VY(1-3).                   SUBVEC
CLJ                                                                      SUBVEC
      DIMENSION VX(3), VY(3), DVXY(3)                                    SUBVEC
      CALL VLIN ( DVXY, 1. , VX, -1. , VY )                              SUBVEC
      RETURN                                                             SUBVEC
      END                                                                SUBVEC
```

```
      SUBROUTINE SURRAD(IDETEC,MSM,DD,SPCULR,IUP,JUP,KUP,LUP,ZLAM,         SURRAD
     $  IFIRES,RAD,UPS,UPPS,UCS,UPCS)                                      SURRAD
CCC                                                                        SURRAD
C          SUBROUTINE SURRAD PROVIDES (ESSENTIALLY), AT THE POINT P WHERE  SURRAD
C          THE OPTICAL LINE-OF-SIGHT FROM THE DETECTOR (WHICH IS           SURRAD
C          FICTITIOUS IN THE NBR MODULE) AT POINT Y INTERSECTS THE         SURRAD
C          EARTH'S SURFACE, THE UPWELLING RADIANCE DIRECTED TOWARD THE     SURRAD
C          DETECTOR.  SURRAD PROVIDES TWO COMPONENTS OF THE RADIANCE...    SURRAD
C          (1) THERMALLY EMITTED AND (2) SOURCE (SUN OR FIREBALL)          SURRAD
C          REFLECTED. REFLECTED SKY RADIANCE IS NOT INCLUDED. STRICTLY,    SURRAD
C          THE SOURCE-REFLECTED COMPONENT IS ACTUALLY PROVIDED IN AN       SURRAD
C          UNATTENUATED FORM TOGETHER WITH THE PATH PARAMETERS (AREAL      SURRAD
C          DENSITY U AND UP, WITH P THE PRESSURE), INTEGRATED ALONG THE    SURRAD
C          INCOMING PATH FROM THE SOURCE, REQUIRED AS INPUT TO A COMPU-    SURRAD
C          TATION OF THE MOLECULAR ABSORPTION OVER A TOTAL PATH.           SURRAD
C          THE AEROSOL TRANSMITTANCE ALONG THE INCOMING PATH FROM THE      SURRAD
C          SOURCE IS ALSO PROVIDED.                                        SURRAD
CCC                                                                        SURRAD
C          THE STATISTICAL CLOUD SUBMODEL HAS NOW BEEN INCLUDED.           SURRAD
C          SEE SUBROUTINE UPWELL FOR COMMENTS.                             SURRAD
C          NOTE THAT THE INPUT PARAMETERS FOR POINT C IN POSITN COMMON     SURRAD
C          AND IKM IN UPWELS COMMON FACILITATE PROVIDING, AS               SURRAD
C          ADDITIONAL OUTPUTS FOR THE PATH FROM THE SUN TO POINT C AT      SURRAD
C          12-KM ALTITUDE, THE PATH PARAMETERS UCS AND UPCS AND THE        SURRAD
C          AEROSOL TRANSMITTANCE TASC(LUP).                                SURRAD
CCC                                                                        SURRAD
C          INPUT PARAMETERS                                                SURRAD
C             ARGUMENT LIST                                                SURRAD
C                IDETEC - FLAG FOR NATURE OF DETECTOR LOCATION             SURRAD
C                         = 1  IF DETECTOR IS AT A SATELLITE POSITION      SURRAD
C                              (SATLAT,SATLON,SATALT) SPECIFIED IN         SURRAD
C                              SATELL COMMON                               SURRAD
C                         = 2  IF DETECTOR IS AT A POSITION (DETLAT,       SURRAD
C                              DETLON,DETALT) SPECIFIED IN TECTOR COMMON.  SURRAD
C                              THIS LATTER OPTION IS USED WHEN SUBROUTINE  SURRAD
C                              SURRAD IS CALLED FROM SUBROUTINE UPWELL.    SURRAD
C                   MSM - INDEX FOR CATEGORY OF SURFACE MATERIAL (SEE      SURRAD
C                         SUBROUTINE ESURF FOR DEFINITIONS)                SURRAD
C                    DD - ADDITIONAL DESCRIPTOR FOR SELECTED SURFACE       SURRAD
C                         MATERIAL (SEE SUBROUTINE ESURF FOR DEFINITIONS)  SURRAD
C             SPCULR - LOGICAL PARAMETER                                   SURRAD
C                    .TRUE.  COMPUTE COORDINATES OF SPECULAR REFLECTION    SURRAD
C                    POINT ON A SMOOTH HORIZONTAL WATER SURFACE            SURRAD
C                    .FALSE. DO NOT COMPUTE COORDINATES OF SPECULAR        SURRAD
C                    REFLECTION POINT                                      SURRAD
C                EACH OF THE FOLLOWING FOUR INDICES SHOULD BE SET TO       SURRAD
C                UNITY IN A CALL FROM ANY ROUTINE OTHER THAN SUBROUTINE    SURRAD
C                UPWELL.                                                   SURRAD
C                IUP - ALTITUDE-LOOP INDEX IN SUBROUTINE UPWELL            SURRAD
C                JUP - NADIR-LOOP INDEX IN SUBROUTINE UPWELL               SURRAD
C                KUP - AZIMUTH-LOOP INDEX IN SUBROUTINE UPWELL             SURRAD
C                LUP - WAVENUMBER-LOOP INDEX IN SUBROUTINE UPWELL          SURRAD
C                  ZLAM - WAVELENGTH,  MICROMETERS                         SURRAD
C                IFIRES - FLAG FOR NUMBER OF FIREBALLS                     SURRAD
C                         = 0  IF NO FIREBALL IS TO BE INCLUDED            SURRAD
C                              (AS IS THE CASE WHEN SUBROUTINE SURRAD IS   SURRAD
C                              CALLED FROM SUBROUTINE UPWELL.)             SURRAD
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C                   .GT. 0  IF IFIRES FIREBALLS ARE TO BE INCLUDED  SURRAD
C                      WITH POSITION AND RADIANT INTENSIT          SURRAD
C                      SPECIFIED IN FIRBAL COMMON                  SURRAD
C     TECTOR COMMON  (USED WITH SUBROUTINE UPWELL)                 SURRAD
C       DETLAT - DETECTOR NORTH LATITUDE, RADIANS                  SURRAD
C       DETLON - DETECTOR EAST LONGITUDE, RADIANS                  SURRAD
C       DETALT - DETECTOR ALTITUDE, KM                             SURRAD
C     FIRBAL COMMON  (NOT USED WITH SUBROUTINE UPWELL)             SURRAD
C        FBLAT(I) - FIREBALL-I NORTH LATITUDE, RADIANS             SURRAD
C        FBLON(I) - FIREBALL-I EAST LONGITUDE, RADIANS             SURRAD
C        FBALT(I) - FIREBALL-I ALTITUDE, KM                        SURRAD
C       FBRINT(I) - FIREBALL-I SPECTRAL RADIANT INTENSITY,         SURRAD
C                   WATTS/(SR CM-1)                                SURRAD
C     POSITN COMMON                                                SURRAD
C       POSLAT - NORTH LATITUDE OF POINT P AT WHICH LINE-OF-       SURRAD
C                SIGHT INTERSECTS EARTH'S SURFACE, RADIANS         SURRAD
C       POSLON - EAST LONGITUDE OF POINT P AT WHICH LINE-OF-       SURRAD
C                SIGHT INTERSECTS EARTH'S SURFACE, RADIANS         SURRAD
C       POSALT - ALTITUDE OF POINT P AT WHICH LINE-OF-SIGHT        SURRAD
C                INTERSECTS EARTH'S SURFACE, KM                    SURRAD
C       C12LAT - NORTH LATITUDE OF POINT C AT WHICH LINE-OF-       SURRAD
C                SIGHT INTERSECTS THE 12-KM ALTITUDE SURFACE,      SURRAD
C                RADIANS                                           SURRAD
C       C12LON - EAST LONGITUDE OF POINT C AT WHICH LINE-OF-       SURRAD
C                SIGHT INTERSECTS THE 12-KM ALTITUDE SURFACE,      SURRAD
C                RADIANS                                           SURRAD
C       C12ALT - ALTITUDE OF POINT C AT WHICH LINE-OF-SIGHT        SURRAD
C                INTERSECTS 12-KM ALTITUDE SURFACE, KM             SURRAD
C     SATELL COMMON  (NOT USED WITH SUBROUTINE UPWELL)             SURRAD
C       SATLAT - SATELLITE NORTH LATITUDE, RADIANS                 SURRAD
C       SATLON - SATELLITE EAST LONGITUDE, RADIANS                 SURRAD
C       SATALT - SATELLITE ALTITUDE, KM                            SURRAD
C     SOLARP COMMON                                                SURRAD
C       SOLLAT - SUBSOLAR POINT NORTH LATITUDE, RADIANS            SURRAD
C       SOLLON - SUBSOLAR POINT EAST LONGITUDE, RADIANS            SURRAD
C     SOURCE COMMON                                                SURRAD
C       THE VARIABLES IN THIS COMMON ARE RETURNED FROM A CALL TO   SURRAD
C       SUBROUTINE RINOUT.  CURRENTLY (APRIL 1980) ONLY THE SUN    SURRAD
C       IS USED AS A SOURCE FOR SUBROUTINE SURRAD.  FIREBALLS      SURRAD
C       ARE NEVER USED IN THE CALL TO SUBROUTINE SURRAD FROM       SURRAD
C       SUBROUTINE UPWELL.                                         SURRAD
C                                                                  SURRAD
C       SRCZEN(1) - ZENITH ANGLE OF RAY INCOMING TO POINT P FROM   SURRAD
C                   THE SUN, RADIANS                               SURRAD
C       SRCZEN(L+1), L=1,IFIRES  (NOT USED WITH SUB. UPWELL)       SURRAD
C                 - ZENITH ANGLE OF RAY INCOMING TO POINT P FROM   SURRAD
C                   FIREBALL-L, RADIANS                            SURRAD
C        SRCSR(L+1), L=1,IFIRES  (NOT USED WITH SUB. UPWELL)       SURRAD
C                 - SLANT RANGE FROM FIREBALL-L TO POINT P, KM     SURRAD
C     UPWELS COMMON                                                SURRAD
C       NWAVE(JBAND)                                               SURRAD
C               - NUMBER OF WAVENUMBERS AT WHICH THE UPWELLING     SURRAD
C                 SPECTRAL RADIANCE IS TO BE COMPUTED FOR          SURRAD
C                 BROAD-BAND LOOP-INDEX JBAND                      SURRAD
C        IDAYV - INDEX FOR DAYLIGHT CONDITION AT SUB-V-POINT       SURRAD
C              = 0  IF SOLAR ZENITH ANGLE .GT. 90 DEGREES          SURRAD
C              = 1  IF SOLAR ZENITH ANGLE .LE. 90 DEGREES          SURRAD
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C               IKM - INDEX FOR NUMBER OF ALTITUDES AT WHICH
C                       CALCULATIONS ARE MADE WHEN CLOUDS ARE INCLUDED.
C                       (SET IN SUBROUTINE UPWELL)
C          XYZCOM COMMON
C                 NS - NUMBER OF BOUNDARY ALTITUDES USED IN
C                       SUBROUTINE SHELLS
C          DATA STATEMENT
C             NSPECS - NUMBER OF SPECIES IN MOLECULAR TRANSMITTANCE
C                       MODEL
C              NTEMP - NUMBER OF TEMPERATURE BINS IN MOLECULAR
C                       TRANSMITTANCE MODEL
CCC
C       OUTPUT PARAMETERS
C          ARGUMENT LIST
C             RAD(1) - RADIANCE EMITTED FROM POINT P TOWARD DETECTOR,
C                         WATTS/(CM**2 SR CM-1)
C             RAD(2) - RADIANCE OF SOLAR REFLECTED RADIATION (WITH
C                       INCOMING RAY UNATTENUATED), W/(CM**2 SR CM-1)
C             RAD(L+2), L=1,IFIRES  (NOT USED WITH SUBROUTINE UPWELL)
C                     - RADIANCE OF FIREBALL-L RADIATION REFLECTED
C                       TOWARD DETECTOR (WITH INCOMING RAY UNATTEN-
C                       UATED),  WATTS/(CM**2 SR CM-1)
C             UPS(I,N,1) - AREAL DENSITY FOR TEMPERATURE I AND SPECIES
C                            N ALONG INCOMING SOLAR PATH TO POINT   ON
C                            EARTH'S SURFACE,  CM AT STP
C                             (COMPUTED ONLY FOR LUP=1)
C             UPS(I,N,L+1), L=1,IFIRES  (NOT USED IN NBR MODULE)
C                     - AREAL DENSITY FOR TEMPERATURE I AND SPECIES N
C                       ALONG PATH FROM FIREBALL-L TO POINT P ON
C                       EARTH'S SURFACE,  CM AT STP
C                       (COMPUTED ONLY FOR LUP=1)
C             UPPS(I,N,1) - PATH PARAMETER UP (PRODUCT OF U AND
C                             PRESSURE P) FOR TEMPERATURE I AND SPECIES
C                             N ALONG INCOMING SOLAR PATH TO POINT P ON
C                             EARTH'S SURFACE,  ATM-CM AT STP
C                              (COMPUTED ONLY FOR LUP=1)
C             UPPS(I,N,L+1), L=1,IFIRES (NOT USED IN NBR MODULE)
C                     - PATH PARAMETER UP (PRODUCT OF U AND PRESSURE P)
C                       FOR TEMPERATURE I AND SPECIES N ALONG PATH FROM
C                       FIREBALL-L TO POINT P ON EARTH'S SURFACE,
C                       ATM-CM AT STP
C                        (COMPUTED ONLY FOR LUP=1)
C           UCS(I,N), - SIMILAR TO UPS(I,N,1) AND UPPS(I,N,1)
C             UPCS(I,N)     EXCEPT POINT P IS REPLACED BY POINT C.
C          AIRSOL COMMON
C               TASP(LUP)  LUP=1,NWAVE(JBAND)
C                     - AEROSOL TRANSMITTANCE FOR INCOMING SOLAR RAY TO
C                       POINT P ON GROUND.
C               TASC(LUP)  LUP=1,NWAVE(JBAND)
C                     - AEROSOL TRANSMITTANCE FOR INCOMING SOLAR RAY TO
C                       POINT C AT 12-KM ALTITUDE.
C             TAFP(L) - AEROSOL TRANSMITTANCE FOR INCOMING RAY FROM
C                       FIREBALL-L TO POINT P ON GROUND
C          SOLARP COMMON
C             SOLIRR(K)  K=1,NWAVE(JBAND)
C                     - SOLAR SPECTRAL IRRADIANCE AT THE TOP OF THE
C                       EARTH'S ATMOSPHERE AT WAVENUMBER-INDEX K
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C                         WATTS / ( CM**2 CM-1 )                              SURRAD    173
CCC                                                                           SURRAD    174
      DIMENSION  RF(3),RP(3),RC(3),RS(3),PLNCK(10)                            SURRAD    175
      DIMENSION  DD(7),RAD(12),UPS(10,10,11),UPPS(10,10,11),                  SURRAD    176
     $                         UCS(10,10)    ,UPCS(10,10)                     SURRAD    177
      DIMENSION  DS(100),XFRACS(100),INDX(100)                                SURRAD    178
      COMMON/AIRSOL/  TASP(10),TASC(10),TAFP(10)                              AIRSOL      2
      COMMON/FIRBAL/  FBLAT(10),FBLON(10),FBALT(10),FBRINT(10)                FIRBAL      2
      COMMON/POSITN/  POSLAT,POSLON,POSALT,SPCLAT,SPCLON                      POSITN      2
     $               ,C12LAT,C12LON,C12ALT                                    POSITN      3
      COMMON/SATELL/  SATLAT,SATLON,SATALT,SATZEN,SATAZI                      SATELL      2
      COMMON/SOLARP/  SOLLAT,SOLLON,SOLIRR(10)                                SOLARP      2
      COMMON/SOURCE/  SRCLAT,SRCLON,SRCALT,SRCFLG,SRCZEN(11),SRCSR(11)        SOURCE      2
      COMMON/TECTOR/  DETLAT,DETLON,DETALT,DETZEN,DETAZI(11)                  TECTOR      2
      COMMON/UPWELS/ UPWALT,UPWLON,UPWLAT,NALT(5),ZKM(13,5),NNADIR,NAZI,      UPWELS      2
     *               NWAVE(5),IDAYV,CLDFLG,UPRADN(13,10,5),WV(10,5),IKM,      UPWELS      3
     *               NBANDS                                                   UPWELS      4
      COMMON/UPWELS1/                                                         UPWELS      5
     2                R010(6,10),R010A(6,10,10),R010N(6,10),                  UPWELS      6
     3                R025(6,10),R025A(6,10,10),R025N(6,10),                  UPWELS      7
     4                R050(6,10),R050A(6,10,10),R050N(6,10),                  UPWELS      8
     5                R090(6,10),R090A(6,10,10),R090N(6,10),                  UPWELS      9
     6                R100(6,10),R100A(6,10,10),R100N(6,10)                   UPWELS     10
     7                          ,ARCVA(6,10,10),ARCVN(6,10)                   UPWELS     11
      COMMON/UPWELS2/ JBAND1                                                  XYZCOM      2
      COMMON/UPWELS3/ UPRAD(6,10),UPRADA(13,10,10)                            XYZCOM      3
      COMMON/ XYZCOM/ ITMTE,LTMTE,NS,HSHELL(81),TPX(81,12),                   XYZCOM      4
     1                U(10,10,2),UP(10,10,2),NMOLS,FACT                       XYZCOM      5
      LOGICAL  FIRST,SPCULR,ESURF1                                            SURRAD    188
      DATA  RSUN / 1.495979E+08 /                                             SURRAD    189
      DATA  NSPECS,NTEMP / 10,10 /                                            SURRAD    190
CC                                                                            SURRAD    191
CC        SUBROUTINE SURRAD IS CALLED FROM SUBROUTINE UPWELL FOR ALL          SURRAD    192
CC        VALUES OF I,J,K,L.  HOWEVER, SWITCHES ELIMINATE REDUNDANT           SURRAD    193
CC        CALCULATIONS.  FOR EXAMPLE,                                         SURRAD    194
CC         * CALL TO FUNCTION PLANCK DEPENDS ONLY ON L.                       SURRAD    195
CC         * CALL TO SUBROUTINE SOLRAD DEPENDS ONLY ON L.                     SURRAD    196
CC         * PATH PARAMETERS FOR PATH FROM POINT P TO SUN ARE                 SURRAD    197
CC           INDEPENDENT OF L AND ARE ASSUMED (TO A GOOD APPROXIMATION)       SURRAD    198
CC           TO BE INDEPENDENT OF I,J,K.                                      SURRAD    199
CC           LIKEWISE FOR POINT C, EXCEPT THAT ITS ALTITUDE IS NOT 0.0        SURRAD    200
CC           BUT 12 KM.                                                       SURRAD    201
CC         * AEROSOL TRANSMITTANCE FROM POINT P TO SUN DEPENDS ONLY ON L      SURRAD    202
CC           AND THE (ASSUMED) SINGLE PATH.                                   SURRAD    203
CC         * AEROSOL TRANSMITTANCE FROM POINT C TO SUN DEPENDS ONLY ON L      SURRAD    204
CC           AND THE (ASSUMED) SINGLE PATH.                                   SURRAD    205
CC                                                                            SURRAD    206
      IF( LUP.GT.1 )  GO TO 5                                                 SURRAD    207
CC                                                                            SURRAD    208
CC        DETERMINE WHETHER DETECTOR IS IN SATELLITE SPECIFIED IN             SURRAD    209
CC        SATELL COMMON.  IDETEC=2 WHEN SUBROUTINE UPWELL CALLS               SURRAD    210
CC        SUBROUTINE SURRAD.                                                  SURRAD    211
      IF( IDETEC.EQ.2 )  GO TO 1                                              SURRAD    212
CC                                                                            SURRAD    213
CC        DETECTOR IS AT SATELLITE, SO RESET DETECTOR LOCATION.               SURRAD    214
      DETLAT = SATLAT                                                         SURRAD    215
      DETLON = SATLON                                                         SURRAD    216
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      DETALT = SATALT                                                   SURRAD
CC         FIRST, CONSIDER ONLY THE SUN AS A SOURCE AND ALSO GET DETECTOR SURRAD
CC         ZENITH AND (IF MSM.GT.2 AND IDAY=1) AZIMUTH ANGLES FOR SUN   SURRAD
CC         AS SOURCE                                                    SURRAD
CC                                                                      SURRAD
    1 CALL RINOUT(MSM, 0 ,IDAY)                                         SURRAD
CC                                                                      SURRAD
CC         NOW HAVE IDAY AT POINT P, DETZEN, (IF IDAY=1) SRCZEN(1), AND SURRAD
CC         (IF IDAY=1 AND MSM.GT.2) DETAZI(1).                          SURRAD
CC                                                                      SURRAD
CC         THE COMPLICATIONS RESULTING FROM THE SOLAR TERMINATOR BEING  SURRAD
CC         VISIBLE FROM POINT V ARE NOT HANDLED IN A COMPLETELY         SURRAD
CC         CONSISTENT WAY.  IF SUBPOINT V' IS IN DAYLIGHT (IDAYV=1), THE SURRAD
CC         DIURNAL CONDITION AT EACH POINT P (AS INDICATED BY INDEX IDAY) SURRAD
CC         IS RECOGNIZED, BUT IF SUBPOINT V' IS IN DARKNESS (IDAYV=0),  SURRAD
CC         THEN DARKNESS IS IMPOSED ON ALL POINTS P BY SETTING IDAY=0.  SURRAD
CC                                                                      SURRAD
      IF( IDAYV.EQ.0 )  IDAY = 0                                        SURRAD
CC                                                                      SURRAD
CC         IFIRES=0 WHEN SUBROUTINE UPWELL CALLS SUBROUTINE SURRAD.     SURRAD
      IF( IFIRES.GT.0 )  CALL RINOUT(MSM,IFIRES,IDAY)                   SURRAD
CC         NOW HAVE ZENITH ANGLES SRCZEN(L+1) AND SLANT RANGES SRCSR(L+1) SURRAD
CC         OF FIREBALL-L (L=1,IFIRES) AND DETECTOR AZIMUTHS DETAZI(L+1). SURRAD
CC                                                                      SURRAD
CC         SET PARAMETERS TO CALL ESURF FOR SUN AS SOURCE.              SURRAD
      THI = -1.0                                                        SURRAD
      PSI = -1.0                                                        SURRAD
      IF( IDAY.EQ.1 )  THI = SRCZEN(1)                                  SURRAD
      IF( (IDAY.EQ.1) .AND. (MSM.GT.2) )  PSI = DETAZI(1)               SURRAD
      THR = DETZEN                                                      SURRAD
      HHH = POSALT                                                      SURRAD
    5 CONTINUE                                                          SURRAD
CC         CALL ESURF WITH ESURF1 SET TO .TRUE. SINCE WE WANT ALL THREE SURRAD
CC         OUTPUTS (SFR, EPSD, TKS).  NOTE THAT EVERY CALL TO ESURF FROM SURRAD
CC         SURRAD (WITHIN NBR MODULE) QUALIFIES AS A FIRST CALL.        SURRAD
      ESURF1 = .TRUE.                                                   SURRAD
      CALL ESURF(THI,THR,PSI,HHH,MSM,DD,SPCULR,ZLAM,IDAY,IFIRES,ESURF1,  SURRAD
     $  SFR,EPSD,TKS)                                                   SURRAD
CC                                                                      SURRAD
CC         BYPASS PRINT OF EPSD AND TKS UNLESS INDICES I, J, K, AND L IN SURRAD
CC         SUBROUTINE UPWELL (KNOWN HERE AS IUP, JUP, KUP, AND LUP) HAVE SURRAD
CC         VALUES OF UNITY.  HOWEVER, WE AND THE CODE RECOGNIZE THE FACT SURRAD
CC         THAT WHEREAS TKS DEPENDS ONLY ON THE SURFACE ALTITUDE, EPSD  SURRAD
CC         DEPENDS ON ANGLE AND WAVELENGTH.                             SURRAD
CC                                                                      SURRAD
      IJK = IUP + JUP + KUP                                             SURRAD
      IJKL = IJK + LUP                                                  SURRAD
CC         WE AVOID USING THE QUANTITY (IKM+JUP+KUP+LUP) BECAUSE THE    SURRAD
CC         MINIMUM VALUE OF IKM IS 0.  THEREFORE, WE USE...             SURRAD
      JK = JUP + KUP                                                    SURRAD
      JKL = JK + LUP                                                    SURRAD
      IF( IJKL .EQ. 4 )  WRITE(6,111) EPSD,TKS                          SURRAD
  111 FORMAT(1H0,1X,* EPSD, TKS = *, 1P2E14.6,*  (FROM SUBROUTINE SURRAD SURRAD
     $, FORMAT 111)*)                                                   SURRAD
CC                                                                      SURRAD
CC         NOW HAVE EPSD, TKS, AND (IF IDAY=1) SFR.                     SURRAD
CC         ALSO, IF IDAY=1, MSM=2, AND SPCULR=.TRUE., WE HAVE (THROUGH  SURRAD
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CC        POSITN COMMON) THE COORDINATES (SPCLAT,SPCLON) OF THE SOLAR     SURRAD
CC        SPECULAR REFLECTION POINT ON A SMOOTH HORIZONTAL WATER SURFACE SURRAD
CC        COMPUTED IN GLITTR. TO FACITATE PRESERVING THESE COORDINATES,  SURRAD
CC        DEFINE NEW VARIABLES.                                          SURRAD
CC                                                                       SURRAD
      SSPLAT = SPCLAT                                                    SURRAD
      SSPLON = SPCLON                                                    SURRAD
CC        IF THESE COORDINATES PROVE TO BE OF INTEREST, ADDITIONAL       SURRAD
CC        PRESERVING VARIABLES WILL BE NEEDED AS SUBROUTINE UPWELL       SURRAD
CC        LOOPS OVER ALTITUDES.                                          SURRAD
CC                                                                       SURRAD
CC        BYPASS CALL TO FUNCTION PLANCK UNLESS INDICES I,J, AND K IN    SURRAD
CC        SUBROUTINE UPWELL (KNOWN HERE AS IUP,JUP, AND KUP) HAVE        SURRAD
CC        VALUES OF UNITY.                                               SURRAD
      IF( IJK.GT.3 )  GO TO 10                                           SURRAD
      W = 1.0E+04/ZLAM                                                   SURRAD
      PLNCK(LUP) = PLANCK(TKS,W)                                         SURRAD
   10 CONTINUE                                                           SURRAD
      RAD(1) = EPSD * PLNCK(LUP)                                         SURRAD
CC        NOW HAVE EMITTED SPECTRAL RADIANCE, RAD(1).                    SURRAD
CC                                                                       SURRAD
      RAD(2) = 0.0                                                       SURRAD
      IF( IDAYV .EQ. 0 )  GO TO 50                                       SURRAD
CC                                                                       SURRAD
CC        ASSUME PATH PARAMETERS FROM POINT P TO THE SUN ARE EFFECTIVELY SURRAD
CC        INDEPENDENT OF THE POINT P LOCATION ON THE SURFACE.  THUS,     SURRAD
CC        BYPASS ZEROING PATH PARAMETERS HERE, AND THEIR COMPUTATION     SURRAD
CC        LATER, UNLESS IUP=JUP=KUP=LUP=1.                               SURRAD
      IF( IJKL.GT.4 )  GO TO 21                                          SURRAD
      DO 20 N=1,NSPECS                                                   SURRAD
      DO 20 I=1,NTEMP                                                    SURRAD
      U PS(I,N,1) = 0.0                                                  SURRAD
      UPPS(I,N,1) = 0.0                                                  SURRAD
   20 CONTINUE                                                           SURRAD
   21 CONTINUE                                                           SURRAD
CC                                                                       SURRAD
CC        ALSO ASSUME PATH PARAMETERS FROM POINT C TO THE SUN ARE        SURRAD
CC        EFFECTIVELY INDEPENDENT OF THE POINT-C LOCATION ON THE 12-KM   SURRAD
CC        ALTITUDE SURFACE.  THUS BYPASS ZEROING PATH PARAMETERS HERE,   SURRAD
CC        AND THEIR COMPUTATION LATER, UNLESS IKM=JUP=KUP=LUP=1 .        SURRAD
      IF( ( IKM .NE. 1 ) .OR. ( JKL .GT. 3 ) )  GO TO 23                 SURRAD
      DO 22 N=1,NSPECS                                                   SURRAD
      DO 22 I=1,NTEMP                                                    SURRAD
      U CS(I,N) = 0.0                                                    SURRAD
      UPCS(I,N) = 0.0                                                    SURRAD
   22 CONTINUE                                                           SURRAD
   23 CONTINUE                                                           SURRAD
CC                                                                       SURRAD
CC        IF SUN IS PRESENT, GET THE SOLAR SPECTRAL IRRADIANCE           SURRAD
CC        E (W/(CM**2 CM-1)) AT THE TOP OF THE ATMOSPHERE.               SURRAD
CC        BYPASS CALL TO SUBROUTINE SOLRAD UNLESS IUP=JUP=KUP=1.         SURRAD
      IF( IJK.GT.3 )  GO TO 25                                           SURRAD
      CALL SOLRAD(3,W,E)                                                 SURRAD
      SOLIRR(LUP) = E                                                    SURRAD
      NWAVEJ = NWAVE(JBAND1)                                             SURRAD
      IF( LUP .EQ. NWAVEJ )  WRITE(6,125)  (SOLIRR(LP),LP=1,NWAVEJ)      SURRAD
  125 FORMAT (1H0,28X,77H* * * SOLAR SPECTRAL IRRADIANCE SOLIRR(L), (L=1 SURRAD
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     $,NWAVEJ), W/(CM**2 CM-1) * * */48X,*(FROM SUBROUTINE SURRAD, FORMA SURRAD
     $T 125)*/2X,1P(10E12.4))                                           SURRAD
   25 CONTINUE                                                          SURRAD
CC                                                                      SURRAD
CC        COMPUTE SPECTRAL RADIANCE OF (UNATTENUATED) DIRECT SOLAR      SURRAD
CC        RADIATION REFLECTED FROM EARTH SURFACE AT POINT P TOWARDS     SURRAD
CC        POINT V.                                                      SURRAD
      RAD(2) = SFR * SOLIRR(LUP) * COS(THI)                             SURRAD
CC                                                                      SURRAD
      IF( IJKL .GT. 4 )  GO TO 27                                       SURRAD
CC                                                                      SURRAD
CC        PREPARE TO GET PATH PARAMETERS FOR PATH FROM POINT P TO SUN,  SURRAD
CC        WHICH CARRIES THROUGH TO STATEMENT LABEL 41.                  SURRAD
CC                                                                      SURRAD
CC        OBTAIN EARTH-CENTERED CARTESIAN COORDINATES OF POINT P.       SURRAD
      CALL GEOXYZ(POSALT,POSLAT,POSLON,RP(1),RP(2),RP(3))               SURRAD
      CALL VLIN(RP,1.0E+05,RP,0.0,0.0)                                  SURRAD
CC                                                                      SURRAD
CC        NEED TO DETERMINE LOCATION OF SUN.                            SURRAD
      CALL GEOXYZ(RSUN,SOLLAT,SOLLON,RS(1),RS(2),RS(3))                 SURRAD
      CALL VLIN(RS,1.0E+05,RS,0.0,0.0)                                  SURRAD
CC        HAVE NOW DETERMINED RP AND RS.                                SURRAD
CC                                                                      SURRAD
CC        INITIALIZE NC SO THAT DS(1) WILL BE SET TO 0.0 IN SUBROUTINE  SURRAD
CC        STEP.                                                         SURRAD
      NC = 0                                                            SURRAD
      CALL STEPS( RP,RS,NC,DS,XFRACS,INDX )                             SURRAD
CC        NOW HAVE NC, DS, XFRACS, AND INDX FOR PATH FROM S TO P.       SURRAD
CC                                                                      SURRAD
CC        INITIALIZE LOGICAL VARIABLE, FIRST, IN PREPARATION FOR FIRST  SURRAD
CC        CALL TO SUBROUTINE PATH.                                      SURRAD
      FIRST = .TRUE.                                                    SURRAD
   27 CONTINUE                                                          SURRAD
CC                                                                      SURRAD
      IF( IJK .GT. 3 )  GO TO 31                                        SURRAD
CC        BEFORE STARTING DO-30 LOOP, OBTAIN THE AEROSOL EXTINCTION     SURRAD
CC        COEFFICIENT AT THE INITIAL ENDPOINT OF THE PATH.              SURRAD
      TASP(LUP) = 1.0                                                   SURRAD
      L1 = INDX(1)    $    L2 = INDX(2)                                 SURRAD
      HSP = XFRACS(1) * HSHELL(L1) + (1.-XFRACS(1)) * HSHELL(L2)        SURRAD
      CALL AEROSOL ( HSP,ZLAM,XKSCT,XKABS,GBAR )                        SURRAD
      XKEXTP = XKSCT + XKABS                                            SURRAD
      DO 30 J=1,NC                                                      SURRAD
CC        ON THE PASS FOR WHICH J=NC, DS(NC+1) WILL BE -1.0, INDICATING SURRAD
CC        THAT THE LAST SEGMENT HAS BEEN PROCESSED.  (THE LOOP COULD    SURRAD
CC        HAVE BEEN FROM J=1 TO J=NC-1 AND THE FOLLOWING TEST           SURRAD
CC        ELIMINATED.)                                                  SURRAD
      IF( DS(J+1).LT.0.0 )  GO TO 30                                    SURRAD
      IF( IJKL .EQ. 4 )  CALL PATH( FIRST,INDX(J),DS(J+1),XFRACS(J) )   SURRAD
      L1 = INDX( J )    $    L2 = INDX(J+1)                             SURRAD
      HSQ = XFRACS(J+1) * HSHELL(L2) + (1.-XFRACS(J+1)) * HSHELL(L1)    SURRAD
      CALL AEROSOL ( HSQ,ZLAM,XKSCT,XKABS,GBAR )                        SURRAD
      XKEXTQ = XKSCT + XKABS                                            SURRAD
      XKEXT = ACCUM( 2,0.,DS(J+1),XKEXTP,XKEXTQ,0.,DS(J+1) ) / DS(J+1)  SURRAD
      TASP(LUP) = TASP(LUP) * EXP( -XKEXT*DS(J+1) )                     SURRAD
      XKEXTP = XKEXTQ                                                   SURRAD
   30 CONTINUE                                                          SURRAD
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   31 CONTINUE                                                          SURRAD
CC        NOW HAVE PATH PARAMETERS U AND UP FOR SOLAR RAY TO POINT P.   SURRAD
CC        SINCE THESE PATH PARAMETERS ARE INDEPENDENT OF WAVELENGTH,    SURRAD
CC        THEY NEED BE COMPUTED ONLY ONCE.                              SURRAD
CC        ALSO HAVE AEROSOL TRANSMITTANCE, TASP(LUP), FOR SOLAR RAY TO  SURRAD
CC        POINT P, WHICH IS WAVELENGTH DEPENDENT.                       SURRAD
      IF( IJKL .GT. 4 )  GO TO 41                                       SURRAD
CC        REDEFINE VARIABLES.                                           SURRAD
      DO 40 N=1,NSPECS                                                  SURRAD
      DO 40 I=1,NTEMP                                                   SURRAD
      U PS(I,N,1) = U (I,N,2)                                           SURRAD
      UPPS(I,N,1) = UP(I,N,2)                                           SURRAD
   40 CONTINUE                                                          SURRAD
      WRITE(6,140)                                                      SURRAD
  140 FORMAT (1H0,44X,43H* * * PATH PARAMETERS, POINT P TO SUN * * */46X SURRAD
     $,*(FROM SUBROUTINE SURRAD, FORMATS 140,142)*/2X,*TEMPERATURE/SPECI SURRAD
     $ES.   ((UPS(M,N,1),N=1,NSPECS),M=1,2)*)                           SURRAD
      WRITE(6,141) ((M, (U PS(M,N,1),N=1,NSPECS)),M=1,2)                SURRAD
  141 FORMAT (2X,I3,1P10E12.4)                                          SURRAD
      WRITE(6,142)                                                      SURRAD
  142 FORMAT (1H0,1X,*TEMPERATURE/SPECIES. ((UPPS(M,N,1),N=1,NSPECS),M=1 SURRAD
     $,2)*)                                                             SURRAD
      WRITE(6,141) ((M, (UPPS(M,N,1),N=1,NSPECS)),M=1,2)                SURRAD
   41 CONTINUE                                                          SURRAD
CC                                                                      SURRAD
CC                                                                      SURRAD
CC        PARAMETERS FOR PATH FROM S TO C NEED BE DONE ONLY ONCE.       SURRAD
      IF( ( IKM .NE. 1 ) .OR. ( JK .GT. 2 ) )  GO TO 50                 SURRAD
      IF( LUP .GT. 1 )  GO TO 42                                        SURRAD
CC                                                                      SURRAD
CC        PREPARE TO GET PATH PARAMETERS FOR PATH FROM POINT C TO SUN.  SURRAD
CC                                                                      SURRAD
CC        OBTAIN EARTH-CENTERED CARTESIAN COORDINATES OF POINT C.       SURRAD
      CALL GEOXYZ(C12ALT,C12LAT,C12LON,RC(1),RC(2),RC(3))               SURRAD
      CALL VLIN(RC,1.0E+05,RC,0.0,0.0)                                  SURRAD
CC                                                                      SURRAD
      NC = 0                                                            SURRAD
      CALL STEPS( RC,RS,NC,DS,XFRACS,INDX )                             SURRAD
CC        NOW HAVE NC, DS, XFRACS, AND INDX FOR PATH FROM S TO C.       SURRAD
      FIRST = .TRUE.                                                    SURRAD
   42 CONTINUE                                                          SURRAD
CC                                                                      SURRAD
      TASC(LUP) = 1.0                                                   SURRAD
      L1 = INDX(1)    $    L2 = INDX(2)                                 SURRAD
      HSP = XFRACS(1) * HSHELL(L1) + (1.-XFRACS(1)) * HSHELL(L2)        SURRAD
      CALL AEROSOL ( HSP,ZLAM,XKSCT,XKABS,GBAR )                        SURRAD
      XKEXTP = XKSCT + XKABS                                            SURRAD
      DO 44 J=1,NC                                                      SURRAD
      IF( DS(J+1) .LT. 0.0 )  GO TO 44                                  SURRAD
      IF( LUP .EQ. 1 )  CALL PATH( FIRST,INDX(J),DS(J+1),XFRACS(J) )    SURRAD
      L1 = INDX( J )    $    L2 = INDX(J+1)                             SURRAD
      HSQ = XFRACS(J+1) * HSHELL(L2) + (1.-XFRACS(J+1)) * HSHELL(L1)    SURRAD
      CALL AEROSOL ( HSQ,ZLAM,XKSCT,XKABS,GBAR )                        SURRAD
      XKEXTQ = XKSCT + XKABS                                            SURRAD
      XKEXT = ACCUM( 2,0.,DS(J+1),XKEXTP,XKEXTQ,0.,DS(J+1) ) / DS(J+1)  SURRAD
      TASC(LUP) = TASC(LUP) * EXP( -XKEXT*DS(J+1) )                     SURRAD
      XKEXTP = XKEXTQ                                                   SURRAD
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   44 CONTINUE                                                          SURRAD
CC        NOW HAVE PATH PARAMETERS U AND UP FOR SOLAR RAY TO POINT C.    SURRAD
CC        SINCE THESE PATH PARAMETERS ARE INDEPENDENT OF WAVELENGTH,     SURRAD
CC        THEY NEED BE COMPUTED ONLY ONCE.                               SURRAD
CC        ALSO HAVE AEROSOL TRANSMITTANCE, TASC(LUP), FOR SOLAR RAY TO   SURRAD
CC        POINT C, WHICH IS WAVELENGTH DEPENDENT.                        SURRAD
      IF( LUP .GT. 1 )  GO TO 50                                        SURRAD
CC        REDEFINE VARIABLES.                                            SURRAD
      DO 46 N=1,NSPECS                                                  SURRAD
      DO 46 I=1,NTEMP                                                   SURRAD
      U CS(I,N) = U (I,N,2)                                             SURRAD
      UPCS(I,N) = UP(I,N,2)                                             SURRAD
   46 CONTINUE                                                          SURRAD
      WRITE(6,146)                                                      SURRAD
  146 FORMAT (1H0,44X,43H* * * PATH PARAMETERS, POINT C TO SUN * * */46X SURRAD
     $,*(FROM SUBROUTINE SURRAD, FORMATS 146,148)*/2X,*TEMPERATURE/SPECI SURRAD
     $ES.   ((UCS(I,N),N=1,NSPECS),I=1,2)*)                             SURRAD
      WRITE(6,141) ((I, (U CS(I,N),N=1,NSPECS)),I=1,2)                  SURRAD
      WRITE(6,148)                                                      SURRAD
  148 FORMAT (1H0,1X,*TEMPERATURE/SPECIES. ((UPCS(I,N),N=1,NSPECS),I=1,2 SURRAD
     $)*)                                                               SURRAD
      WRITE(6,141) ((I, (UPCS(I,N),N=1,NSPECS)),I=1,2)                  SURRAD
   50 CONTINUE                                                          SURRAD
CC                                                                       SURRAD
CC        THE REMAINING PORTION OF THIS SUBROUTINE, NOT TO BE USED WITH  SURRAD
CC        SUBROUTINE UPWELL, IS AVOIDED BY CALLING SUBROUTINE SURRAD     SURRAD
CC        WITH IFIRES=0 .                                                SURRAD
CC                                                                       SURRAD
      IF( IFIRES.EQ.0 )  RETURN                                         SURRAD
CC                                                                       SURRAD
CC-------------------------------------------------------------------- SURRAD
CC        NOW CONSIDER THE FIREBALLS AS SOURCES.                         SURRAD
CC        NOTE THAT THE NATURAL CLOUD MODULE IS NOT INVOLVED WITH THE    SURRAD
CC        REMAINING PORTION OF THIS ROUTINE.                             SURRAD
CC                                                                       SURRAD
CC        ASSUME THAT LUP (IN ARGUMENT LIST) ALSO SERVES AS A WAVELENGTH SURRAD
CC        INDEX.                                                         SURRAD
      DO 99 L=1,IFIRES                                                  SURRAD
CC        GET THE (UNATTENUATED) IRRADIANCE, EFIRE, OF FIREBALL-L AT     SURRAD
CC        SLANT RANGE SRCSR(L+1), IN WATTS/(CM**2 CM-1).                 SURRAD
CC                                                                       SURRAD
      EFIRE = FBRINT(L)/(1.E+10*SRCSR(L+1)*SRCSR(L+1))                  SURRAD
CC                                                                       SURRAD
CC        SET PARAMETERS TO CALL ESURF.                                  SURRAD
      THI = SRCZEN(L+1)                                                 SURRAD
      PSI = DETAZI(L+1)                                                 SURRAD
CC        CALL ESURF WITH ESURF1 SET TO .FALSE. SINCE THIS IS NOT THE    SURRAD
CC        FIRST CALL FROM THIS ROUTINE AND THUS WE DO NOT NEED A         SURRAD
CC        RECOMPUTATION OF EPSD AND TKS.                                 SURRAD
      ESURF1 = .FALSE.                                                  SURRAD
CC        CALL ESURF WITH SPCULR SET TO .FALSE. UNDER THE TENTATIVE      SURRAD
CC        ASSUMPTION THAT WE WILL NOT NEED THE SPECULAR REFLECTION       SURRAD
CC        POINTS FOR FIREBALLS (WHICH CAN BE COMPUTED IN GLITTR IF       SURRAD
CC        MSM=2).  IF THERE IS INTEREST IN KNOWING SUCH REFLECTION       SURRAD
CC        POINTS WE WILL NEED TO ESTABLISH APPROPRIATE PRESERVING        SURRAD
CC        VARIABLES.                                                     SURRAD
      SPCULR = .FALSE.                                                  SURRAD
```

```
      CALL ESURF(THI,THP,PSI,HHH,HSM,DO,SPCULR,ZLAM,IDAY,IFIRES,ESURFI,   SURRAD
     $  SFR,EPSO,TKS)                                                     SURRAD
      RAD(L+2) = SFR*EFIRE*COS(THI)                                       SURRAD
CC         NOW HAVE UNATTENUATED REFLECTED RADIANCE, RAD(L+2), AT         SURRAD
CC         POINT P DUE TO FIREBALL-L.  NEED PATH PARAMETERS.              SURRAD
      IF( LUP .GT. 1 )  GO TO 60                                          SURRAD
      CALL GEOXYZ( FBALT(L),FBLAT(L),FBLON(L),RF(1),RF(2),RF(3))          SURRAD
      CALL VLIN(RF,1.0E+05,RF,0.0,0.0)                                    SURRAD
      NC = 0                                                              SURRAD
      CALL STEPS( RP,RF,NC,DS,XFRACS,INDX )                               SURRAD
CC         NOW HAVE NC,DS,XFRACS, AND INDX.                               SURRAD
      FIRST = .TRUE.                                                      SURRAD
   60 CONTINUE                                                            SURRAD
      TAFP(L) = 1.0                                                       SURRAD
      L1 = INDX(1)    $   L2 = INDX(2)                                    SURRAD
      HSP = XFRACS(1) * HSHELL(L1) + (1.-XFRACS(1)) * HSHELL(L2)          SURRAD
      CALL AEROSOL ( HSP,ZLAM,XKSCT,XKABS,GBAR )                          SURRAD
      XKEXTP = XKSCT + XKABS                                              SURRAD
      DO 70 J=1,NC                                                        SURRAD
      IF( DS(J+1).LT.0.0 )  GO TO 70                                      SURRAD
      IF( LUP .EQ. 1 )  CALL PATH( FIRST,INDX(J),DS(J+1),XFRACS(J) )      SURRAD
      L1 = INDX( J )    $   L2 = INDX(J+1)                                SURRAD
      HSQ = XFRACS(J+1) * HSHELL(L2) + (1.-XFRACS(J+1)) * HSHELL(L1)      SURRAD
      CALL AEROSOL ( HSQ,ZLAM,XKSCT,XKABS,GBAR )                          SURRAD
      XKEXTQ = XKSCT + XKABS                                              SURRAD
      XKEXT = ACCUM( 2,0.,DS(J+1),XKEXTP,XKEXTQ,0.,DS(J+1) ) / DS(J+1)    SURRAD
      TAFP(L) = TAFP(L) * EXP( -XKEXT*DS(J+1) )                           SURRAD
      XKEXTP = XKEXTQ                                                     SURRAD
   70 CONTINUE                                                            SURRAD
CC         NOW HAVE PATH PARAMETERS U AND UP FOR FIREBALL-L RAY TO        SURRAD
CC         POINT P.                                                       SURRAD
CC         ALSO HAVE AEROSOL TRANSMITTANCE, TAFP(L), FOR FIREBALL-L       SURRAD
CC         RAY FROM RF TO RP.                                             SURRAD
      IF( LUP .GT. 1 )  GO TO 99                                          SURRAD
CC         REDEFINE VARIABLES.                                            SURRAD
      DO 80 N=1,NSPECS                                                    SURRAD
      DO 80 I=1,NTEMP                                                     SURRAD
      UPS(I,N,L+1) = U (I,N,2)                                            SURRAD
      UPPS(I,N,L+1) = UP(I,N,2)                                           SURRAD
   80 CONTINUE                                                            SURRAD
   99 CONTINUE                                                            SURRAD
      RETURN                                                              SURRAD
      END                                                                 SURRAD
```

```
      SUBROUTINE TANGEO(HA1,GC1,GL1,XE21,YN21,ZV21,HA2,GC2,GL2)
CCC
C       SUBROUTINE TANGEO (A MODIFIED HARC ROUTINE CALLED XYZGEO),
C       GIVEN THE GEOGRAPHIC COORDINATES OF POINT 1 AND THE TANGENT-
C       PLANE COORDINATES OF POINT 2 WITH RESPECT TO POINT 1, PROVIDES
C       THE GEOGRAPHIC COORDINATES OF POINT 2.
CCC
C         INPUTS FROM CALL STATEMENT
C            HA1  = ALTITUDE OF POINT 1,  CM
C            GC1  = COLATITUDE OF POINT 1,  RADIANS
C            GL1  = EAST LONGITUDE OF POINT 1,  RADIANS
C            XE21 = X COORDINATE OF POINT 2 RELATIVE TO POINT 1,  CM
C            YN21 = Y COORDINATE OF POINT 2 RELATIVE TO POINT 1,  CM
C            ZV21 = Z COORDINATE OF POINT 2 RELATIVE TO POINT 1,  CM
C         OUTPUTS
C            HA2  = ALTITUDE OF POINT 2,  CM
C            GC2  = COLATITUDE OF POINT 2,  RADIANS
C            GL2  = EAST LONGITUDE OF POINT 2,  RADIANS
CCC
C         RESTRICTIONS...
C         POINTS 1 AND/OR 2 MAY NOT LIE ON NORTH-SOUTH POLAR AXIS
CCC
      DATA  PI,RE / 3.141592653590,6.37103E+08 /
CCC
      GR2Z = RE+HA1+ZV21
      GR2 = SQRT(XE21**2 + YN21**2 + GR2Z**2)
      HA2 = GR2-RE
      COSGC1 = COS(GC1)
      SINGC1 = SIN(GC1)
      COSGC2 = (GR2Z*COSGC1 + YN21*SINGC1)/GR2
      SINGC2 = SQRT(1.0-COSGC2**2)
      SINGLD = XE21/(GR2*SINGC2)
      COSGLD = (GR2Z/GR2 - COSGC1*COSGC2)/(SINGC1*SINGC2)
      GC2 = ATAN2( SINGC2,COSGC2 )
      GLD = ATAN2( SINGLD,COSGLD )
      GL2 = GL1+GLD
      RETURN
      END
```

```
      SUBROUTINE TRANS( NTEMP, M, U, UP, FK, WDL, WDH, TAU, ABC, TTBL,  TRANS
     1     FAST, FILPOS )                                                TRANS
C                                                                        TRANS
CLJ                                                                      TRANS
CLJ   INPUT PARAMETERS                                                   TRANS
CLJ      ARGUMENT LIST                                                   TRANS
CLJ          NTEMP = NUMBER OF TEMPERATURES IN ATMOSPHERIC               TRANS
CLJ                  TRANSMITTANCE MODEL (10, SET IN CALL FROM EITHER    TRANS
CLJ                  ATMRAD OR TRNSCO)                                   TRANS
CLJ              M = INDEX FOR MODE OF TRANSMITTANCE CALCULATION.        TRANS
CLJ                  COULD BE 1,2,....,15 . WITHIN THE NATURAL           TRANS
CLJ                  BACKGROUND RADIATION MODULE (WHERE TRANS IS CALLED  TRANS
CLJ                  FROM ATMRAD, TRNSCO, AND UPWELL), M IS ALWAYS 1.    TRANS
CLJ                  (IN CALLS FROM PROGRAM EMISCAT, M IS 1, 2, AND IS   TRANS
CLJ                  ALLOWED VALUES UP TO 15.)                           TRANS
CLJ                  IN SUBROUTINE TRANS, M=1 LIMITS USE OF THE U AND    TRANS
CLJ                  UP ARRAYS TO THEIR FIRST HALVES.  THIS IS           TRANS
CLJ                  CONSISTENT WITH THE FACT THAT WITHIN THE NBR        TRANS
CLJ                  MODULE, SUBROUTINE TRANS IS ALWAYS CALLED WITH M    TRANS
CLJ                  SET TO 1, U SET TO U(1,1,2), AND UP SET TO          TRANS
CLJ                  UP(1,1,2).  THIS IS ALSO TRUE FOR CALLS WITH M=1    TRANS
CLJ                  FROM EMISCAT.  BUT THERE, WHEN M.GE.2, THE CALLS    TRANS
CLJ                  ARE WITH U AND UP, I. E., THE ENTIRE ARRAYS.        TRANS
CLJ       U(I,N,1) = AREAL DENSITY FOR TEMPERATURE I AND                 TRANS
CLJ                  SPECIES N,  CM AT STP  (I=1,NTEMP , N=1,NSPEC)      TRANS
CLJ      UP(I,N,1) = PATH PARAMETER UP (PRODUCT OF U AND PRESSURE FOR    TRANS
CLJ                  TEMPERATURE I AND SPECIES N,  ATM-CM AT STP         TRANS
CLJ                   (I=1,NTEMP , N=1,NSPEC)                            TRANS
CLJ          FK(M) =                                                     TRANS
CLJ                  (FK(M) IS USED ONLY IF M.GE.3 .  CURRENTLY, M IS    TRANS
CLJ                  SET TO 1 IN CALLS TO TRANS FROM TRNSCO AND ATMRAD)  TRANS
CLJ            WDL = LOWEST WAVENUMBER IN DETECTOR INTERVAL BEING        TRANS
CLJ                  USED,  1/CM                                         TRANS
CLJ            WDH = HIGHEST WAVENUMBER IN DETECTOR INTERVAL BEING       TRANS
CLJ                  USED,  1/CM                                         TRANS
CLJ           FAST - LOGICAL VARIABLE DETERMINING COMPLEXITY OF          TRANS
CLJ                  TRANSMISSION CALCULATION.  IN CALLS TO SUBROUTINE   TRANS
CLJ                  TRANS (FROM SUBROUTINES ATMRAD, TRNSCO, AND UPWELL  TRANS
CLJ                  WITHIN THE NBR MODULE AND FROM PROGRAM EMISCAT      TRANS
CLJ                  OUTSIDE THE NBR MODULE), FAST IS SET TO TRNSOPT.    TRANS
CLJ                  =.TRUE., TRANSMITTANCE IS BASED ON SINGLE-LEVEL     TRANS
CLJ                          GROUPS AND STATISTICAL BANDS.  BAND-MODEL   TRANS
CLJ                          PARAMETERS COMPUTED BY SUBROUTINE TRANSB    TRANS
CLJ                          FOR TRNSOPT=.TRUE. ARE MATCHED TO USER'S    TRANS
CLJ                          SPECTRAL INTERVAL.                          TRANS
CLJ                  =.FALSE., TRANSMITTANCE IS BASED ON MULTIPLE-LEVEL  TRANS
CLJ                          GROUPS AND RANDOM ELSASSER BANDS.  BAND-    TRANS
CLJ                          MODEL PARAMETERS COMPUTED BY SUBROUTINE     TRANS
CLJ                          TRANSB FOR TRNSOPT=.FALSE. ARE FOR A        TRANS
CLJ                          HIGHER RESOLUTION THAN THE USER'S SPECTRA   TRANS
CLJ                          INTERVAL, A FACT TAKEN INTO ACCOUNT IN      TRANS
CLJ                          COMPUTING THE TRANSMITTANCE.                TRANS
CLJ         FILPOS = FILE POSITION.  SET TO 1.E+04 IN CALLS FROM         TRANS
CLJ                  SUBROUTINES TRNSCO AND ATMRAD.                      TRANS
CLJ      XY COMMON                                                       TRANS
CLJ          TT(I) = TEMPERATURE ARRAY IN ATMOSPHERIC TRANSMISSION       TRANS
CLJ                  MODEL, SET AS DATA IN THE DRIVER PROGRAM.           TRANS
```

```
CLJ      XYZCOM COMMON
CLJ           LTMTE = BINARY FILE CONTAINING THE BAND-MODEL PARAMETERS
CLJ                   WHICH WERE DERIVED IN SUBROUTINE TRANSB FROM THE
CLJ                   BASIC 5-(1/CM)-RESOLUTIOI DATA.
CLJ                   LTMTE IS IDENTICAL TO TAPOT, THE FILE WRITTEN
CLJ                   BY TRANSB.   (SEE TRANSB.)
CLJ             * * * * * * * * * * *
CLJ                   FOR EACH READ OF THE LTMTE FILE, THE 202 WORDS
CLJ                   ARE STORED AS...
CLJ             WTL,  = LOWER AND HIGHER WAVENUMBERS OF INTERVAL,  CM-1
CLJ             WTH
CLJ                   FOR I=1,10 , IS=1,10
CLJ        SOD(I,IS) = MEAN ABSORPTION COEFFICIENT FOR SPECIES-IS AT
CLJ                   TEMPERATURE-INDEX-I FOR THE WAVENUMBER INTERVAL,
CLJ                   1/CM AT STP
CLJ        DEI(I,IS) = INVEP.  OF MEAN LINE-SPACING PARAMETER, OR THE
CLJ                   EFFECTIVE LINE DENSITY,  LINES/(1/CM)
CLJ             * * * * * * * * * * *
CLJ           NSPEC = NMOLS, THE NUMBER OF SPECIES.  SET IN DRIVER.
CLJ   OUTPUT PARAMETERS
CLJ      ARGUMENT LIST
CLJ        TAU(N,M) = TRANSMITTANCE FOR SPECIES N
CLJ                   (N=1,NSPEC ,  M=1,15)   (BUT M=1 FOR NBR MODULE)
CLJ        ABC(N,M) = OPTICAL DEPTH FOR SPECIES N,   DIMENSIONLESS
CLJ                   (N=1,NSPEC ,  M=1,15)   (BUT M=1 FOR NBR MODULE)
CLJ         TTBL(M) = MOLECULAR TRANSMITTANCE FOR MODE M
      DIMENSION U(NTEMP,10,2), UP(NTEMP,10,2), FK(M), NSRAY(10),
     1     GHAT(13,5), F(13,10), G(13,10), THETA(10), CF(13,10,10),
     2     CG(13,10,10), TAU(10,M), XMW(10), SOD(10,10), DEI(10,10),
     3     ALS(10), ABC(10,M), TTBL(M)
C
      COMMON / XY / TT(10)
      COMMON / XYZCOM / ITMTE, LTMTE, XXX(1454), NSPEC, FACT
C     COMMON / CONCON / PI, RBODY,       ...........
C
      LOGICAL TABLIN, FAST
C
      DATA  SOD / 100 * 0. /, DEI / 100 * 0. /
      DATA NSRAY / 4, 3, 12, 10, 10, 11, 4, 0, 5, 2 /
      DATA GHAT / 1 , 2., 4., 6., 10., 14., 19., 25., 33., 42., 53.,
     1     66., 80., 1., 1., 3., 3., 6., 7., 10., 12., 14., 17., 19.,
     2     0., 0., 1., 2., 3., 6., 7., 10., 15., 17., 21.. 28., 30., 0.,
     3     0., 1., 2., 4., 6., 10., 14., 20., 27., 36., 46., 58., 72.,
     4     0., 1., 1., 3., 3., 3., 6., 7 * 0. /
      DATA THETA / 2740., 3420., 850., 1080., 1015., 960., 3123., 0.,
     1     2300., 5350. /
      DATA ALS / .04, .04, .08, .10, .11, .07, .06, .06, .04, .06 /
      DATA A1 / 0.3480242 /, A2 / -.0958798 /, A3 / 0.7478556 /
      DATA P / 0.47047 /
      DATA XMW / 30., 30., 44., 46., 48., 44., 28., 16., 18., 17. /
      DATA TABLIN / .FALSE. /, WLP / 0. /, WHP / 0. /
      DATA PI / 3.14159265 /
C
CLJ        ENTRY TRANS1  IS PROVIDED BY SAI (12/29/78) TO AVOID CONFLICT
CLJ        IN SUBROUTINE UPWELL BETWEEN THE ARRAY TRANS IN COMMON CLDWT
CLJ        AND THE CALL TO SUBROUTINE TRANS.
      ENTRY TRANS1
```

```
      M10 = M * 10
C
      DO 31 I = 1, M10
      ABC(I,1) = 0.
      TAU(I,1) = 0.
   31 CONTINUE
C
      IF ( TABLIN .OR. FAST ) GO TO 27
C
C         INITAILIZATIONS
C
C         LOOP OVER SPECIES
C
      DO 1 IS = 1, NSPEC
      NS = NSRAY(IS) + 1
C
C         LOOP OVER ENERGY BINS
C
      DO 2 J = 1, NS
      F(J,IS) = 1.
      GO TO ( 3, 3, 4, 4, 4, 4, 3, 4, 4, 3 ), IS
C
    3 F(J,IS) = J
C
    4 GO TO ( 5, 6, 7, 8, 9, 10, 6, 11, 12, 5 ), IS
C
    5 G(J,IS) = 2.
      GO TO 2
C
    6 G(J,IS) = 1.
      GO TO 2
C
    7 G(J,IS) = GHAT(J,1)
      GO TO 2
C
    8 G(J,IS) = GHAT(J,2) * 100.
      GO TO 2
C
    9 G(J,IS) = GHAT(J,3) * 100.
      GO TO 2
C
   10 G(J,IS) = GHAT(J,4)
      GO TO 2
C
   11 G(J,IS) = 100.
      GO TO 2
C
   12 G(J,IS) = GHAT(J,5) * 100.
    2 CONTINUE
C
    1 CONTINUE
C
C         LOOP OVER TEMPERATURES
C
      DO 13 I = 1, NTEMP
C
C         LOOP OVER SPECIES
```

```
C
      DO 14 IS = 1, NSPEC
C
      NS = NSRAY(IS) + 1
      FSUM = 0.
C
C           LOOP OVER ENERGY BINS
C
      DO 15 J = 1, NS
      FJ = J - 1
      FSUM = FSUM + F(J,IS) * G(J,IS) * EXP( -THETA(IS) * FJ / TT(I) )
   15 CONTINUE
C
      FISUM = 0.
C
C           LOOP OVER ENERGY BINS
C
      DO 16 J = 1, NS
      CF(J,IS,I) = 1.
      FJ = J - 1
      CF(J,IS,I) = F(J,IS) * G(J,IS) * EXP( -THETA(IS) * FJ / TT(I) )
     $      / FSUM
      FISUM = FISUM + SQRT( CF(J,IS,I) * G(J,IS) )
   16 CONTINUE
C
C           LOOP OVER ENERGY BINS
C
      DO 17 J = 1, NS
      CG(J,IS,I) = 1.
      FJ = J - 1
      CG(J,IS,I) = G(J,IS) / FISUM **2
   17 CONTINUE
C
   14 CONTINUE
C
   13 CONTINUE
C
      TABLIN = .TRUE.
C
   27 IF ( FAST  .AND.  ( WDL .NE. WLP  .OR.  WDH .NE. WHP ) ) GO TO 23
      IF ( FILPOS .LE. WDL ) GO TO 24
C
      REWIND LTMTE
      WTL = 0.
      WTH = 0.
      GO TO 24
C
C           READ SPECTRAL DATA FILE
C
   23 READ (LTMTE) WTL, WTH, ( ( SOD(I,IS), I = 1, NTEMP ),
     $      ( DEI(I,IS), I = 1, NTEMP ), IS = 1, NSPEC )
      FILPOS = WTL
      WHP = WDH
      WLP = WDL
C
   24 OLAP = FRAC( WDL, WDH, WTL, WTH )
      IF ( WTL .GE. WDH ) RETURN
```

```
      IF ( OLAP .LE. 0. ) GO TO 23                                      TRANS
C                                                                       TRANS
      W = ( WTL + WTH ) / 2.                                            TRANS
C                                                                       TRANS
C           LOOP OVER PATH SEGMENTS                                     TRANS
C                                                                       TRANS
CLJ         IN NBR MODULE USAGE, M IS SET TO 1 IN CALLS TO SUBROUTINE   TRANS
CLJ         TRANS, BUT IN CALLS TO TRANS FROM PROGRAM EMISCAT, M IS SET TO TRANS
CLJ         1, 2, AND MAY BE UP TO 15.                                  TRANS
      DO 22 K = 1, M                                                    TRANS
C                                                                       TRANS
C           LOOP OVER SPECIES                                           TRANS
C                                                                       TRANS
      DO 19 IS = 1, NSPEC                                               TRANS
      ADS = 3.58E-7 * W * SQRT( 273. / XMW(IS) )                        TRANS
      NS = NSRAY(IS) + 1                                                TRANS
      IF ( FAST ) NS = 1                                                TRANS
      XS = 0.                                                           TRANS
C                                                                       TRANS
C           LOOP OVER ENERGY BINS                                       TRANS
C                                                                       TRANS
CLJ         NOTE THAT NS=1 FOR FAST = TRNSOPT = .TRUE.  .               TRANS
      DO 19 J = 1, NS                                                   TRANS
      XWL = 0.                                                          TRANS
      SUMC = 0.                                                         TRANS
      SUMD = 0.                                                         TRANS
C                                                                       TRANS
C           LOOP OVER TEMPERATURES                                      TRANS
C                                                                       TRANS
C           CALCULATE OPTICAL DEPTH IN WEAK-LINE APPROXIMATION          TRANS
C                                                                       TRANS
      DO 20 I = 1, NTEMP                                                TRANS
      IF ( M .GE. 3 ) GO TO 29                                          TRANS
CLJ         SINCE M=1 IN NBR-MODULE USAGE, K HAS THE SINGLE VALUE OF 1. TRANS
CLJ         THUS, WE ARE SETTING U(I,IS,1) AND UP(I,IS,1) INTO US AND   TRANS
CLJ         UPS, RESPECTIVELY.                                          TRANS
      US = U(I,IS,K)                                                    TRANS
      UPS = UP(I,IS,K)                                                  TRANS
      GO TO 30                                                          TRANS
C                                                                       TRANS
CLJ         THE FOLLOWING EXPRESSION IS USED ONLY IF M.GE.3, AS MAY OBTAIN TRANS
CLJ         FOR CALLS TO TRANS FROM PROGRAM EMISCAT.  NBR-MODULE USAGE HAS TRANS
CLJ         M=1, SO U(I,IS,2) AND UP(I,IS,2) ARE NOT USED IN SUBROUTINE TRANS
CLJ         TRANS, NOR IS THE ARRAY FK, FOR THE NBR MODULE.             TRANS
   29 US = ( 1. - FK(K) ) * U(I,IS,1) + FK(K) * U(I,IS,2)               TRANS
      UPS = ( 1. - FK(K) ) * UP(I,IS,1) + FK(K) * UP(I,IS,2)            TRANS
C                                                                       TRANS
   30 IF ( US .EQ. 0. ) GO TO 20                                        TRANS
      IF ( FAST ) GO TO 36                                              TRANS
      SODI = CF(J,IS,I) * SOD(I,IS)                                     TRANS
      DEII = CG(J,IS,I) * DEI(I,IS)                                     TRANS
      GO TO 32                                                          TRANS
C                                                                       TRANS
   36 SODI = SOD(I,IS)                                                  TRANS
      DEII = DEI(I,IS)                                                  TRANS
C                                                                       TRANS
   32 XWL = XWL + SODI * US                                             TRANS
```

```
      SUMC = SUMC + SQRT( 273. / TT(I) ) * DEII * SODI * UPS
      SUMD = SUMD + SQRT( TT(I) / 273. ) * DEII * SODI * US
   20 CONTINUE
C
      IF ( XWL .LE. 1.E-100 ) GO TO 34
C
C          CALCULATE OPTICAL DEPTH IN AN APPROXIMATE
C          RANDOM ELSASSER MODEL
C
      ACSJ = ALS(IS) / XWL * SUMC
      ADSJ = ADS / XWL * SUMD
      IF ( FAST ) GO TO 25
      U2 = PI * XWL **2 / ( 4. * G(J,IS) **2 * ( 1. + XWL /
     $     ( 4. * ACSJ ) ) )
      TL = 1. / ( 1. + P * SQRT( U2 ) )
      XRE = -G(J,IS) * ( ALOG( A1 * TL + A2 * TL **2 + A3 * TL **3 ) -
     $     U2 )
C
C          CALCULATE OPTICAL DEPTH FOR LORENTZ LINES
C
      XL = AMIN1( XRE, XWL )
      GO TO 33
C
   25 XL = XWL / SQRT( 1. + XWL / ( 4. * ACSJ ) )
C
C          CALCULATE OPTICAL DEPTH FOR DOPLER LINES
C
   33 XD = 1.7 * ADSJ * SQRT( ALOG( 1. + ( XWL / ( 1.7 * ADSJ ) ) **2 ))
      A = ( 1. - ( XL / XWL ) **2 ) **2
      B = ( 1. - ( XD / XWL ) **2 ) **2
      IF ( A + B .LE. 1.E-15 ) GO TO 21
      Y = SQRT( A * B / ( B + A - A * B ) )
C
C          CALCULATE OPTICAL DEPTH OF SPECIES
C
      XS = XS + XWL * SQRT( 1. - Y )
      GO TO 19
C
   21 XS = XS + XWL
CLJ        STATEMENT 19 IS FOR THE ENERGY-BIN LOOP ON INDEX J.  FOR
CLJ        FAST = .TRUE., THIS LOOP IS DONE ONLY ONCE.
   19 CONTINUE
C
C
C          CALCULATE TRANSMITTANCE OF SPECIES
C
      ABC(IS,K) = ABC(IS,K) + XS * OLAP
      TAU(IS,K) = TAU(IS,K) + EXP( -XS ) * OLAP
      GO TO 18
   34 TAU(IS,K) = TAU(IS,K) + OLAP
CLJ        STATEMENT 18 IS FOR THE SPECIES LOOP ON INDEX IS.
   18 CONTINUE
C
CLJ        STATEMENT 22 IS FOR THE SO-CALLED PATH-SEGMENT LOOP ON INDEX
CLJ        K.  FOR NBR-MODULE USAGE, K EQUALS ONLY 1.
   22 CONTINUE
C
```

```
      IF ( WTH .LT. .9999999 * WDH ) GO TO 23                           TRANS
C                                                                       TRANS
      DO 35 K = 1, M                                                    TRANS
      TTBL(K) = 1.                                                      TRANS
      DO 35 IS = 1, NSPEC                                               TRANS
CLJ         THE FOLLOWING TWO-LINE CHANGE, RECEIVED IN TWO INSTALLMENTS TRANS
CLJ         FROM L. EWING ON 3/20/79 AND A. KLEIN ON 9/10/79, AFFECTS THE TRANS
CLJ         EMISSION CALCULATION IN SUBROUTINE ATMRAD.                  TRANS
      IF( ( TAU(IS,K) .LT. 0.9999 ) .AND. ( TAU(IS,K) .GT. 0.0001 ) )   TRANS
     $  ABC(IS,K) = -ALOG( TAU(IS,K) )                                  TRANS
   35 TTBL(K) = TTBL(K) * TAU(IS,K)                                     TRANS
C                                                                       TRANS
      RETURN                                                            TRANS
      END                                                               TRANS
```

```
      SUBROUTINE TRANSB ( LBAND )                                       TRANSB
C                                                                       TRANSB
C          *TRANSB* ELIMINATES UNNECESSARY SPECTRAL DATA FROM           TRANSB
C          THE EXTERNAL FILE.  THE TYPE OF SPECTRAL COVERING GENERATED  TRANSB
C          DEPENDS ON TRNSOPT.  IF TRNSOPT IS .TRUE. , THE FASTEST      TRANSB
C          BUT LEAST ACCURATE CALCULATIONS WILL BE DONE.                TRANSB
C                                                                       TRANSB
CLJ                                                                     TRANSB
CLJ   INPUT PARAMETERS                                                  TRANSB
CLJ      ARGUMENT LIST                                                  TRANSB
CLJ           LBAND - LIST HEADER VARIABLE (LHV) FOR WAVELENGTH BANDS   TRANSB
CLJ                   DATASET-BN (NO. 114).  STRICTLY, LBAND IS THE     TRANSB
CLJ                   POINTER (I.E., IT CONTAINS THE (Q-ARRAY) ADDRESS  TRANSB
CLJ                   FOR THE LIST HEADER OF THE WAVELENGTH BANDS       TRANSB
CLJ                   DATASET-BN.                                       TRANSB
CLJ                   IN GRC USAGE, LBAND IS STORED AS WORD-12 OF       TRANSB
CLJ                   DATASET-ST (NO. 111).                             TRANSB
CLJ                   IN THE SAI STAND-ALONE VERSION OF THE NBR MODULE, TRANSB
CLJ                   DATASET-ST (NO. 111) IS NOT USED, BUT LBAND IS    TRANSB
CLJ                   STILL GENERATED IN PROGRAM DRVUPW AND USED AS THE TRANSB
CLJ                   LHV FOR DATASET-BN.                               TRANSB
CLJ      XYZCOM COMMON                                                  TRANSB
CLJ           ITMTE = AUXILIARY INPUT DATA FILE NUMBER,  (=2 IN DRVUPW) TRANSB
CLJ           LTMTE = AUXILIARY OUTPUT DATA FILE NUMBER, (=3 IN DRVUPW) TRANSB
CLJ      OPTION COMMON                                                  TRANSB
CLJ         TRNSOPT - LOGICAL VARIABLE AFFECTING (A) PROCEDURE FOR      TRANSB
CLJ                   CONVERTING THE BASIC 5-(1/CM)-RESOLUTION BAND-    TRANSB
CLJ                   MODEL PARAMETERS TO THOSE FOR THE USER-SPECIFIED  TRANSB
CLJ                   RESOLUTION AND (B) POSSIBLE REDUNDANCY OF OUTPUT  TRANSB
CLJ                   DATA IF USER-SELECTED BANDS OVERLAP WITH COMMON   TRANSB
CLJ                   SPECTRAL INTERVALS.                               TRANSB
CLJ                   =.TRUE., TRANSB PROVIDES...                       TRANSB
CLJ                    (A) IN-BAND (MORE PRECISELY, ''IN-INTERVAL'')    TRANSB
CLJ                    AVERAGED BAND-MODEL PARAMETERS.  (THERE IS NO    TRANSB
CLJ                    LIMIT ON THE ALLOWED COARSENESS OF THE           TRANSB
CLJ                    RESOLUTION.  IF RESOLUTION FINER THAN 5-(1/CM) IS TRANSB
CLJ                    REQUESTED, THE CODE WILL COMPUTE ANSWERS, BUT    TRANSB
CLJ                    THEY MAY HAVE LITTLE OR NO PHYSICAL REALITY.)    TRANSB
CLJ                    (B) BAND-MODEL PARAMETERS FOR EACH INTERVAL      TRANSB
CLJ                    WITHIN A BAND (EVEN THOUGH BANDS MAY OVERLAP),   TRANSB
CLJ                    AND THE BANDS ARE ORDERED AS IN THE WAVELENGTH   TRANSB
CLJ                    BANDS DATASET-BN (NO. 114).                      TRANSB
CLJ                   =.FALSE., TRANSB PROVIDES...                      TRANSB
CLJ                    (A) BAND-MODEL PARAMETERS AT A (BELOW-DEFINED)   TRANSB
CLJ                    RESOLUTION THAT MAY BE FINER THAN THE REQUESTED  TRANSB
CLJ                    SPECTRAL INTERVALS.  IN THIS CASE THE TRANSB-    TRANSB
CLJ                    GENERATED RESOLUTION (OR SUBINTERVAL) IS 0.5 OF  TRANSB
CLJ                    THE NARROWEST USER-SPECIFIED WAVENUMBER INTERVAL, TRANSB
CLJ                    BUT WITHIN THE RANGE OF 5 TO 50 (1/CM).  THE     TRANSB
CLJ                    LOWER EDGE OF THE FIRST OUTPUT INTERVAL LIES AT  TRANSB
CLJ                    THE LOWER EDGE OF THE LOWEST WAVENUMBER SPECTRAL TRANSB
CLJ                    INTERVAL.                                        TRANSB
CLJ                    (B) NON-REDUNDANT INFORMATION FOR INTERVALS IN   TRANSB
CLJ                    OVERLAPPING BANDS.  (IF BANDS DON'T OVERLAP,     TRANSB
CLJ                    THERE IS NOTHING TO ELIMINATE, OF COURSE.)       TRANSB
CLJ                    NOTE.  FOR ADDITIONAL INFORMATION REGARDING USE  TRANSB
CLJ                    OF THESE BAND-MODEL PARAMETERS, SEE COMMENTS     TRANSB
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CLJ                   UNDER THE LOGICAL VARIABLE FAST IN SUBROUTINE      TRANSB
CLJ                   TRANS.                                             TRANSB
CLJ    ''DATASET-BN''                                                    TRANSB
CLJ         ** NOTE * THE SPELLING (BN) IS AN UNFORTUNATE ARTIFACT FROM  TRANSB
CLJ                 * THE ORIGINAL DEVELOPMENT OF THE ROUTINE BY L.      TRANSB
CLJ                 * EWING OF GET.  WE ARE REALLY DEALING WITH WORDS-3, TRANSB
CLJ                 * -4, AND -6 OF THE GRC DICTIONARY DATASET-BI (NO.   TRANSB
CLJ                 * 115) AND NOT DATASET-BN (NO. 114).                 TRANSB
CLJ         WLO BN, = LOWEST AND HIGHEST WAVENUMBERS OF SPECTRAL         TRANSB
CLJ         WHI BN    INTERVAL OVER WHICH BAND-MODEL PARAMETERS ARE TO   TRANSB
CLJ                   BE AVERAGED,  CM-1                                 TRANSB
CLJ       TFLAG BN  = FLAG TO DENOTE WHETHER THE WAVELENGTH OR           TRANSB
CLJ                   WAVENUMBER (CORRESPONDING TO THE ARGUMENT OF       TRANSB
CLJ                   TFLAG BN) IS ASSOCIATED WITH THE FIRST,            TRANSB
CLJ                   INTERMEDIATE, OR LAST SPECTRAL DIVISION IN A BAND  TRANSB
CLJ                   OF (ASCENDING) WAVELENGTHS OR (ASCENDING)          TRANSB
CLJ                   WAVENUMBERS.                                       TRANSB
CLJ                 = 1., FIRST SPECTRAL DIVISION (LOWEST WAVELENGTH) IN TRANSB
CLJ                   A WAVELENGTH BAND OR LAST SPECTRAL DIVISION        TRANSB
CLJ                   (HIGHEST WAVENUMBER) IN A WAVENUMBER BAND          TRANSB
CLJ                 = 0., INTERMEDIATE SPECTRAL DIVISION                 TRANSB
CLJ                 = 2., LAST SPECTRAL DIVISION (HIGHEST WAVELENGTH) IN TRANSB
CLJ                   A WAVELENGTH BAND OR FIRST SPECTRAL DIVISION       TRANSB
CLJ                   (LOWEST WAVENUMBER) IN A WAVENUMBER BAND           TRANSB
CLJ      INPUT BINARY FILE                                               TRANSB
CLJ           TAPIN = EQUIVALENCED TO ITMTE.  CONTAINS BAND-MODEL        TRANSB
CLJ                   PARAMETERS FOR 5-(CM-1) RESOLUTION                 TRANSB
CLJ             WSL = LOWER  WAVENUMBER OF 5-(CM-1) INTERVAL FOR THE SET TRANSB
CLJ                   1997.5(5.0)4997.5  CM-1                            TRANSB
CLJ             WSH = HIGHER WAVENUMBER OF 5-(CM-1) INTERVAL FOR THE SET TRANSB
CLJ                   2002.5(5.0)5002.5  CM-1                            TRANSB
CLJ             FOR I=1,10 , IS=1,10 ...                                 TRANSB
CLJ       SOD(I,IS) = MEAN ABSORPTION COEFFICIENT FOR SPECIES-IS AT      TRANSB
CLJ                   TEMPERATURE-INDEX-I FOR THE 5-(CM-1) INTERVAL      TRANSB
CLJ                   FROM WSL TO WSH,  CM-1 AT STP                      TRANSB
CLJ       DEI(I,IS) = INVERSE OF MEAN LINE-SPACING PARAMETER, OR THE     TRANSB
CLJ                   EFFECTIVE LINE DENSITY, LINES/(CM-1).              TRANSB
CLJ    OUTPUT PARAMETERS                                                 TRANSB
CLJ      OUTPUT BINARY FILE                                              TRANSB
CLJ           TAPOT = EQUIVALENCED TO LTMTE.  CONTAINS BAND-MODEL        TRANSB
CLJ                   PARAMETERS, DERIVED FROM THE 5-(CM-1)-RESOLUTION   TRANSB
CLJ                   DATA, FOR THE USER-SPECIFIED INTERVAL DW EITHER    TRANSB
CLJ                   (A) COMMUNICATED THROUGH THE DATASET-BI IF         TRANSB
CLJ                   TRNSOPT = .TRUE. OR (B) SET BY AN ALGORITHM IF     TRANSB
CLJ                   TRNSOPT = .FALSE.  THE ALGORITHM IS THAT DW EQUALS TRANSB
CLJ                   ONE-HALF OF THE MINIMUM DW COMMUNICATED THROUGH    TRANSB
CLJ                   THE DATASET-BI, BUT NOT LESS THAN 5.0 OR MORE      TRANSB
CLJ                   THAN 50.0 CM-1                                     TRANSB
CLJ             WL, = LOWER AND HIGHER WAVENUMBERS OF                    TRANSB
CLJ             WH    INTERVAL DW,  CM-1                                 TRANSB
CLJ             FOR I=1,10 , IS=1,10 ...                                 TRANSB
CLJ         S(I,IS) = MEAN ABSORPTION COEFFICIENT FOR SPECIES-IS AT      TRANSB
CLJ                   TEMPERATURE-INDEX-I FOR THE INTERVAL DW,           TRANSB
CLJ                   CM-1 AT STP                                        TRANSB
CLJ        DE(I,IS) = INVERSE OF MEAN LINE-SPACING PARAMETER, OR THE     TRANSB
CLJ                   EFFECTIVE LINE DENSITY, LINES/(CM-1)               TRANSB
CLJ                                                                      TRANSB
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      DIMENSION SOD(10,10), DEI(10,10), S(10,10), DE(10,10)
      DIMENSION WLO   BN(1), WHI   BN(1), TFLAG BN(1)
      COMMON QNAREA, QWAREA(10), QFREHD, QNDTST, QNLNKS, QZSIZE,
     1       QNZBLK, QZHEAD, QCOUNT(30), QDSIZE(10), QNSIZE, QLUNIT(10),
     2       QERLUN, QFBITS(2,10), Q(1)
      EQUIVALENCE ( Q, IQ )
      DIMENSION IQ(1)
      COMMON / XYZCOM / ITMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81),
     1                  XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS,
     2                  FACT
      COMMON / OPTION / TRNSOPT
C
CLJ         ** NOTE * THE THREE WORDS WLO BN, WHI BN, AND TFLAG BN ARE
CLJ                   IN REALITY WORDS-3, -4, AND -6 IN THE GRC
CLJ                   DICTIONARY DATASET-BI (NO. 115).  THEIR SPELLING
CLJ                   HERE IS AN ARTIFACT OF THE ORIGINAL PREPARATION OF
CLJ                   THE ROUTINE BY L. EWING OF GET.
      EQUIVALENCE ( Q(3), WLO   BN ), ( Q(4), WHI   BN ),
     *            ( Q(6), TFLAG BN )
      EQUIVALENCE ( ITMTE, TAPIN ), ( LTMTE, TAPOT )
C
      INTEGER TAPIN, TAPOT
      LOGICAL TRNSOPT
C
CLJ       THE INITIALIZED VALUES OF THE NEXT FOUR PARAMETERS WILL BE
CLJ       RESET.  FOR EXAMPLE, WSL AND WSH ARE RESET BY DATA-FILE
CLJ       WAVENUMBERS.
      DW = 1.E10
      WDL = 1.E10
      WSL = 0.
      WSH = 0.
      IBAND = 0
      LINK = LBAND
      IF ( TRNSOPT ) GO TO 13
C
CLJ       SCAN SPECTRAL LIST TO OBTAIN BAND LIMITS AND FINEST RESOLUTION
    9 CALL PREV ( LINK, NBN )
      IF( NBN .EQ. 0 )  GO TO 11
CLJ       LINT, WORD-5 OF GRC DICTIONARY DATASET-BN (NO. 114), IS LHV
CLJ       FOR LIST OF BAND-INTERVAL DATASETS-BI (NO. 115).
      LINT = IQ( NBN + 4 )
CLJ       DATASET INDEX-J IS USED FOR SIMPLICITY INSTEAD OF THE
CLJ       TRADITIONAL INDEX-NBI FOR DATASET-BI.
   10 CALL PREV ( LINT, J )
      IF( J .EQ. 0 )  GO TO 9
CLJ       THE ARGUMENT 3 IN THE CALL TO PUTORA CAUSES SORTING WITH
CLJ       RESPECT TO WLO BN(J).
      IF ( TFLAG BN(J) .NE. 0. ) CALL PUTORA ( IBAND, J, 3 )
      DW = AMIN1( DW, WHI   BN(J) - WLO   BN(J) )
      WDL = AMIN1( WDL, WLO   BN(J) )
      GO TO 10
C
C         SET RESOLUTION FOR OUTPUT FILE.
CLJ       CHOOSE 0.5 OF THE MINIMUM DW, BUT WITHIN 5 TO 50 CM-1 IN ANY
CLJ       EVENT.
   11 DW = AMAX1 ( AMIN1( .5 * DW, 50. ), 5. )
CLJ       INITIALIZE VARIABLES USED BELOW.  DESPITE SPELLING, WH IS THE
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CLJ       SAVED-VALUE OF THE LOW END OF BAND.
      WH = WDL
CLJ       WDL AND WDH ARE THE INITIALIZED VALUES OF THE LOW AND HIGH
CLJ       SIDES OF A CONTINUOUS DETECTOR RANGE.
      WDL = 1.E10
      WDH = 0.
      LAP = 0
      LIMIT = IBAND
C
CLJ       SCAN BAND-LIMITS LIST (WHOSE LHV-WORD IS LIMIT=IBAND) FOR
CLJ       SPECTRAL COVERING.
   12 CALL NEXT ( LIMIT, J )
      IF ( J .EQ. 0 ) GO TO 7
      IF ( TFLAG BN(J) .GE. 2. ) LAP = LAP + 1
CLJ       NOW UPDATE VALUES OF LOW AND HIGH SIDES OF CONTINUOUS DETECTOR
CLJ       RANGE.
      WDL = AMIN1( WDL, WLO   BN(J) )
      WDH = AMAX1( WDH, WHI   BN(J) )
      IF ( AMOD( TFLAG BN(J), 2. ) .EQ. 1. ) LAP = LAP - 1
      IF ( LAP .GT. 0 ) GO TO 12
CLJ       XSKIP IS NONZERO ONLY IF SPECTRAL BANDS HAVE A GAP BETWEEN
CLJ       THEM.
      XSKIP = IFIX( ( WDL - WH ) / DW )
CLJ       NOW SET THE LOWER EDGE OF THE NEW RANGE AFTER THE GAP.
      WH = WH + XSKIP * DW
      GO TO 1
C
C         SCAN SPECTRAL LIST FOR USER DEFINED TABLE RESOLUTION
CLJ       THIS BLOCK OF CODING IS USED ONLY FOR TRNSOPT =.TRUE.
   13 CALL PREV ( LINK, NBN )
      IF( NBN .EQ. 0 )  GO TO 7
CLJ       LINT, WORD-5 OF GRC DICTIONARY DATASET-BN (NO. 114), IS LHV
CLJ       FOR LIST OF BAND-INTERVAL DATASETS-BI (NO. 115).
      LINT = IQ( NBN + 4 )
   14 CALL PREV ( LINT, J )
      IF( J .EQ. 0 )  GO TO 13
      WDL = WLO   BN(J)
      WDH = WHI   BN(J)
      DW = WDH - WDL
      WH = WDL
      IF ( WDL .LT. WSL ) REWIND TAPIN
      IF ( WDL .LT. WSL ) WSH = 0.
      IF ( WDL .LT. WSL ) WSL = 0.
C
C         GENERATE COMPRESSED TABLE
    1 WL = WH
      WH = WH + DW
CLJ       ZERO THE S AND DE ARRAYS.
      CALL XMIT ( -100, 0., S )
      CALL XMIT ( -100, 0., DE )
CLJ       OLAP WILL BE ZERO ON THE FIRST PASS AND POSSIBLY MANY PASSES
CLJ       UNTIL WSL.GT.WL .
    2 OLAP = FRAC( WL, WH, WSL, WSH )
      IF ( OLAP .EQ. 0. ) GO TO 4
C
C         ACCUMULATE SPECTRAL PARAMETERS
CLJ       THE FIRST 10 IS FOR 10 TEMPERATURES FOR THE FIRST SPECIES,
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CLJ       NEXT 10 FOR SECOND SPECIES, ETC.
      DO 3 I=1,100
      IF ( DEI(I,1) .EQ. 0. ) GO TO 3
      DE(I,1) = DE(I,1) + OLAP / DEI(I,1)
      S(I,1) = S(I,1) + OLAP * SOD(I,1) / DEI(I,1)
    3 CONTINUE
CLJ       ON FIRST PASS, WILL DROP THROUGH TEST.  WHEN THE TEST IS
CLJ       SATISFIED, ENOUGH DATA WILL HAVE BEEN ACCUMULATED TO COVER THE
CLJ       WIDTH DW.
    4 IF ( WSH .GE. WH )  GO TO 5
C
C         BRING IN 5 CM-1 TABLE PLANE
CLJ       NOTE THAT FOR A BINARY FILE NO FORMAT IS NEEDED.  READ
CLJ       2+( (10+10)*10 )=202 WORDS AND STORE IN WSL, WSH, ETC.
      READ (TAPIN) WSL, WSH, (( SOD(I,IS), I=1,10 ), ( DEI(I,IS), I=1,10
     $               ), IS=1,10 )
CLJ       NOTE THAT THE EOF FUNCTION IS USED TO TEST FOR AN END-OF-FILE
CLJ       CONDITION ON UNIT TAPIN FOLLOWING AN UNFORMATTED READ.  ZERO
CLJ       IS RETURNED IF NO END-OF-FILE IS ENCOUNTERED, OR A NON-ZERO
CLJ       VALUE IF END-OF-FILE IS ENCOUNTERED.
      IF ( EOF(TAPIN) .EQ. 0. ) GO TO 2
C
C         COMPUTE COMPRESSED SPECTRAL PARAMETERS
    5 DO 6 I=1,100
      IF ( DE(I,1) .EQ. 0. ) GO TO 6
      DE(I,1) = 1. / DE(I,1)
      S(I,1) = S(I,1) * DE(I,1)
    6 CONTINUE
C
C         WRITE COMPRESSED TABLE PLANE
      WRITE (TAPOT) WL, WH, (( S(I,IS), I=1,10 ), ( DE(I,IS), I=1,10 ),
     $               IS=1,10 )
CLJ       THE FOLLOWING THREE STATEMENTS ARE RELEVANT ONLY FOR TRNSOPT=
CLJ       .FALSE. .  THE FIRST WDH IS THE HIGH END OF THE BAND.  IF TEST
CLJ       IS SATISFIED, DO NEXT DW IN BAND.  THE NEXT TWO STATEMENTS
CLJ       COMPRISE AN INITIALIZATION JUST LIKE THAT BEFORE STATEMENT
CLJ       LABEL 12, OF IMPORT ONLY FOR TRNSOPT=.FALSE. .
      IF ( WH .LT. WDH - .001 ) GO TO 1
      WDL = 1.E10
      WDH = 0.
CLJ       NOW DO NEXT SPECTRAL INTERVAL IF TRNSOPT=.TRUE. .  OTHERWISE,
CLJ       CONTINUE WITH SCAN OF THE BAND-LIMITS LIST.
      IF( TRNSOPT )  GO TO 14
      GO TO 12
C
C         CLEAN UP AND RETURN
    7 CALL WIPOUT ( IBAND, 0 )
      ENDFILE TAPOT
      REWIND TAPOT
      REWIND TAPIN
      RETURN
      END
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      SUBROUTINE TRNSCO ( RX, RY, RZ, LBINT, RADSW )                    TRNSCO
C                                                                       TRNSCO
CLJ      *TRNSCO* ESTABLISHES THE TRANSMITTANCE ON A COMPOUND PATH      TRNSCO
C        FROM RX TO RY TO RZ LOCATION VECTORS.                          TRNSCO
CLJ                                                                     TRNSCO
CLJ   IF RADSW=.TRUE., SUBROUTINE ATMRAD WILL BE CALLED TO PERFORM A    TRNSCO
CLJ   RADIANCE CALCULATION.  IF ONE WANTS RADSW=.TRUE., THEN TRNSCO     TRNSCO
CLJ   SHOULD BE CALLED WITH ONLY A STRAIGHT PATH AND NOT A COMPOUND PATH TRNSCO
CLJ   BECAUSE NO ACCOUNT IS TAKEN OF THE SCATTERING EVENT AT THE POINT  TRNSCO
CLJ   RY.                                                               TRNSCO
CLJ                                                                     TRNSCO
C                                                                       TRNSCO
CLJ   INPUT PARAMETERS                                                  TRNSCO
CLJ      ARGUMENT LIST                                                  TRNSCO
CLJ           RX(I) = LOCATION VECTOR OF POINT X, TYPICALLY BUT NOT     TRNSCO
CLJ                   NECESSARILY THE DETECTOR, CM                      TRNSCO
CLJ           RY(I) = LOCATION VECTOR OF POINT Y, TYPICALLY BUT NOT     TRNSCO
CLJ                   NECESSARILY THE SCATTERING SITE, CM               TRNSCO
CLJ           RZ(I) = LOCATION VECTOR OF POINT Z, TYPICALLY BUT NOT     TRNSCO
CLJ                   NECESSARILY THE SOURCE, CM                        TRNSCO
CLJ                   (FOR RX, RY, AND RZ  I=1,3)                       TRNSCO
CLJ           LBINT = WORD NO. 5 (LHV) IN GRC DATASET-BN (NO. 114),     TRNSCO
CLJ                   LIST OF BAND-INTERVAL DATASETS (BI).              TRNSCO
CLJ                   STRICTLY, LBINT IS THE POINTER (I.E., CONTAINS THE TRNSCO
CLJ                   (Q-ARRAY) ADDRESS) FOR THE LIST HEADER OF THE     TRNSCO
CLJ                   BAND-INTERVAL DATASETS-BI CORRESPONDING TO        TRNSCO
CLJ                   DATASET-BN.                                       TRNSCO
CLJ           RADSW = INITIALIZATION SWITCH FOR ATMOSPHERIC VOLUME      TRNSCO
CLJ                   EMISSION CALCULATION.  IS SET IN INPUT TO DRIVER. TRNSCO
CLJ                 = .TRUE., INCLUDE CALL (FROM SUBROUTINE TRNSCO) TO  TRNSCO
CLJ                   SUBROUTINE ATMRAD                                 TRNSCO
CLJ                 = .FALSE., BYPASS CALL TO SUBROUTINE ATMRAD AND     TRNSCO
CLJ                   PERFORM TRANSMITTANCE CALCULATION WITHOUT AIR     TRNSCO
CLJ                   EMISSION                                          TRNSCO
CLJ      DATASET BI  (BAND-INTERVAL DATASET, NO. 115)                   TRNSCO
CLJ           Q(1) = BNLO BI = LOW WAVELENGTH FOR WAVELENGTH-BAND-INDEX TRNSCO
CLJ                      J,  MICRONS                                    TRNSCO
CLJ           Q(2) = BNHI BI = HIGH WAVELENGTH FOR WAVELENGTH-BAND-     TRNSCO
CLJ                      INDEX J,  MICRONS                              TRNSCO
CLJ           Q(3) = WLO  BI = LOW WAVENUMBER FOR WAVELENGTH-BAND-INDEX TRNSCO
CLJ                      J,  CM-1                                       TRNSCO
CLJ           Q(4) = WHI  BI = HIGH WAVENUMBER FOR WAVELENGTH-BAND-     TRNSCO
CLJ                      INDEX J,  CM-1                                 TRNSCO
CLJ      XYZCOM COMMON                                                  TRNSCO
CLJ           LTMTE = BINARY FILE CONTAINING BAND-MODEL PARAMETERS,     TRNSCO
CLJ                   DERIVED FROM THE 5-(CM-1)-RESOLUTION DATA.  (SEE  TRNSCO
CLJ                   SUBROUTINE TRANSB WHERE TAPOT IS EQUIVALENCED TO  TRNSCO
CLJ                   LTMTE.)  HERE IN SUBROUTINE TRNSCO, FILE LTMTE IS TRNSCO
CLJ                   REWOUND FOR USE IN SUBROUTINE TRANS.              TRNSCO
CLJ      OPTION COMMON                                                  TRNSCO
CLJ         TRNSOPT = LOGICAL VARIABLE AFFECTING COMPLEXITY OF MOLECULAR TRNSCO
CLJ                   TRANSMITTANCE CALCULATION (SEE SUBROUTINES TRANSB TRNSCO
CLJ                   AND TRANS).  HERE, TRNSOPT IS USED ONLY IN THE    TRNSCO
CLJ                   ARGUMENT LIST FOR THE CALL TO SUBROUTINE TRANS, A TRNSCO
CLJ                   CALL THAT OCCURS ONLY IF RADSW=FALSE., WHICH IS   TRNSCO
CLJ                   NOT THE CASE FOR THE NBR MODULE.                  TRNSCO
CLJ   OUTPUT PARAMETERS                                                 TRNSCO
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CLJ  *** NOTE ***
CLJ  DESCRIPTION OF THE OUTPUT REQUIRES CARE.
CLJ  1. IN THE (RARE) EVENT THE PATH SHOULD NOT INTERSECT THE
CLJ     ATMOSPHERE, THEN INITIALIZED VALUES OF WORD-5 (IF RADSW=.TRUE.)
CLJ     , WORD-7, AND WORD-8 OF DATASET-BI ARE EXPLICITLY SET HERE IN
CLJ     TRNSCO.
CLJ  2. IN THE USUAL EVENT THAT THE PATH DOES INTERSECT THE ATMOSPHERE,
CLJ     THERE ARE TWO CASES TO CONSIDER.
CLJ  2.1 RADSW=.TRUE. (APPLIES TO NBR MODULE)
CLJ      SUBROUTINE ATMRAD IS CALLED TO EVALUATE WORD-5, -7, -8 OF
CLJ      DATASET-BI, BUT THIS DATASET IS NOT CALLED HERE IN TRNSCO AND
CLJ      THUS IS NOT EXPLICITLY AVAILABLE IN TRNSCO.
CLJ  2.2 RADSW=.FALSE. (DOES NOT APPLY TO NBR MODULE)
CLJ      SUBROUTINE ATMRAD IS NOT CALLED.  HENCE THE CALLS THAT ATMRAD
CLJ      MAKES TO GET THE TRANSMITTANCE CALCULATION DONE MUST BE MADE
CLJ      HERE IN TRNSCO.  IN THIS CASE WORD-7 AND WORD-8 OF DATASET-BI
CLJ      ARE EXPLICITLY AVAILABLE.
CLJ  DEFINITIONS OF WORD-5, -7, AND -8 OF DATASET-BI FOLLOW.
CLJ          Q(5) = BKGND BI = IN-BAND-INTERVAL RADIANCE (DUE TO
CLJ                            ATMOSPHERIC EMISSION) OVER THE ENTIRE
CLJ                            PATH LENGTH (WHICH SHOULD HAVE 1-LEG
CLJ                            AND NOT 2-LEGS),  W/(CM**2 SR BAND-INT)
CLJ          Q(7) = TRANS BI = PRODUCT OF MOLECULAR AND AEROSOL
CLJ                            TRANSMITTANCES OVER THE ENTIRE PATH
CLJ                            LENGTH
CLJ          Q(8) = IDSBX BI = AEROSOL TRANSMITTANCE OVER THE ENTIRE
CLJ                            PATH LENGTH.
CLJ          *** NOTE ***  THIS IS A TEMPORARY USE OF WORD-8 (AND NOT
CLJ                        THE GRC DICTIONARY USE OF WORD-8).  HERE IT
CLJ                        USED TO CARRY INFORMATION TO SUBROUTINE
CLJ                        UPWELL.
CLJ     QNCNC COMMON
CLJ          NCNC = VARIABLE SET TO NC.  SEE COMMENT ABOVE /QNCNC/.
CLJ
      DIMENSION DS(100), XFRACS(100), INDX(100), RX(3), RY(3), RZ(3),
     1          TAU(10), ABC(10)
C
      COMMON QNAREA, QNAREA(10), QFREHD, QNDTST, QNLNKS, QZSIZE,
     1       QNZBLK, QZHEAD, QCOUNT(30), QOSIZE(10), QNSIZE, QLUNIT(10),
     2       QERLUN, QFBITS(2,10), Q(1)
      COMMON / XYZCOM / ITMTE, LTMTE, NS, HSHELL(81), TS(81), PS(81),
     1                  XNSPEC(81,10), U(10,10,2), UP(10,10,2), NMOLS,
     2                  FACT
      COMMON / OPTION / TRNSOPT
CLJ       COMMON QNCNC AND THE LATER STATEMENT IN WHICH NCNC IS SET TO
CLJ       NC ARE ADDED TO FACILITATE BEING ABLE TO CALL THE SAI
CLJ       UPWELLING NATURAL RADIATION MODULE WITH ZERO-KILOMETER
CLJ       ALTITUDE.  FOR MORE INFORMATION SEE COMMENTS PRECEDING LABEL
CLJ       NUMBER 22 IN SUBROUTINE UPWELL OF THAT MODULE.
      COMMON/ QNCNC/  NCNC
      DIMENSION BNLO  BI(1), BNHI  BI(1), WLO   BI(1), WHI   BI(1),
     *          BKGND BI(1), TFLAG BI(1), TRANS BI(1), IDSBX BI(1)
      EQUIVALENCE ( Q(1), BNLO  BI ), ( Q(2), BNHI  BI ),
     *            ( Q(3), WLO   BI ), ( Q(4), WHI   BI ),
     *            ( Q(5), BKGND BI ), ( Q(6), TFLAG BI ),
     *            ( Q(7), TRANS BI ), ( Q(8), IDSBX BI )
C
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```
      LOGICAL RADSW, FIRST, TRNSOPT, LOGIC
C
C           OBTAIN INTEGRATION LIST
      NC = 0
      CALL STEPS ( RX, RY, NC, DS, XFRACS, INDX )
      CALL STEPS ( RY, RZ, NC, DS, XFRACS, INDX )
      NCNC = NC
      IF( NC .GT. 1 )  GO TO 20
CLJ
CLJ
CLJ         PATH DOES NOT INTERSECT ATMOSPHERE.  THUS, ONLY CERTAIN
CLJ         INITIALIZATIONS ARE PERFORMED HERE IN LOOP-10.
      LINT = LBINT
   10 CALL PREVNL ( LINT, J )
      IF ( J .EQ. 0 ) RETURN
      IF( RADSW )  BKGND BI(J) = 0.
      TRANS BI(J) = 1.
CLJ         THE FOLLOWING ADDITIONAL INITIALIZATION IS APPROPRIATE WHEN
CLJ         THE SAI NATURAL BACKGROUND RADIATION MODULE IS CALLED WITH
CLJ         ZERO-KILOMETER ALTITUDE.
      CALL XMIT (-1,1.,IDSBX BI(J))
      GO TO 10
CLJ
CLJ
C           PATH INTERSECTS ATMOSPHERE
CLJ         SET LOGIC FOR FIRST CALL TO ATMRAD AND FIRST FOR FIRST CALL
CLJ         TO PATH.  SET FILPOS AND REWIND FILE LTMTE FOR USE IN TRANS.
   20 LOGIC = .TRUE.
      FIRST = .TRUE.
      FILPOS = 1.E4
      REWIND LTMTE
      DO 30 I=1,NC
CLJ         RECALL THAT DS(NC+1) = -1.0 AND THAT NC-1 = NUMBER OF PATH
CLJ         SEGMENTS.
      IF( DS(I+1) .LT. 0. )  GO TO 30
C           INTEGRATE PATH PROPERTIES
      CALL PATH ( FIRST, INDX(I), DS(I+1), XFRACS(I) )
C           THERMAL EMISSION ON REQUEST
CLJ         *** CAUTION ***
CLJ          F SUBROUTINE TRNSCO IS EXERCISED ON A COMPOUND PATH WITH
CLJ         RADSW=.TRUE., THE TRANSMITTANCE CALCULATION WILL BE CORRECT
CLJ         BUT THE RADIANCE CALCULATION WILL BE INCORRECT BECAUSE NO
CLJ         ACCOUNT HAS BEEN TAKEN OF THE SCATTERING EVENT AT RY.
      IF ( RADSW ) CALL ATMRAD( LOGIC, INDX(I), XFRACS(I), DS(I+1),
     *                          LBINT )
   30 CONTINUE
CLJ         IN NBR MODULE, RADSW=.TRUE., SO WE ARE THROUGH WITH SUBROUTINE
CLJ         TRNSCO.
      IF ( RADSW ) RETURN
CLJ
CLJ
CLJ         **************************************************************
CLJ         REMAINING PORTION OF THIS ROUTINE IS NOT USED IN THE
CLJ         STANDARD MODE OF OPERATING THE NBR MODULE WITH RADSW=.TRUE.
CLJ         **************************************************************
CLJ         ZERO FIRST HALVES OF THE U AND UP ARRAYS.
      CALL XMIT ( -100, 0., U )
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      CALL XMIT ( -100, 0., UP )                                        TRNSCO
CLJ        SCAN SPECTRAL BAND-INTERVAL LIST.                            TRNSCO
      LINT = LBINT                                                      TRNSCO
   40 CALL PREVNL ( LINT, J )                                           TRNSCO
      IF ( J .EQ. 0 ) RETURN                                            TRNSCO
      WL = WLO BI(J)                                                    TRNSCO
      WH = WHI BI(J)                                                    TRNSCO
CLJ        SET MEAN WAVELENGTH FOR CALL TO AEROSOL.                     TRNSCO
      W = 0.5*(WL+WH)                                                   TRNSCO
      WAVEL = 1.E4/W                                                    TRNSCO
C          OBTAIN TRANSMISSION FOR EACH SPECTRAL INTERVAL               TRNSCO
CLJ        GET MOLECULAR TRANSMITTANCE AND TEMPORARILY CALL IT          TRNSCO
CLJ        TRANS BI(J).                                                 TRNSCO
      CALL TRANS ( 10, 1, U(1,1,2), UP(1,1,2), X1, WL, WH, TAU, ABC,    TRNSCO
     *             TRANS BI(J), TRNSOPT, FILPOS )                       TRNSCO
CLJ        INITIALIZE THE AEROSOL TRANSMITTANCE TDST                    TRNSCO
      TDST = 1.                                                         TRNSCO
CLJ        GET THE ALTITUDE AT THE FIRST POINT P ALONG THE TRANSMITTANCE TRNSCO
CLJ        PATH.                                                        TRNSCO
      L1 = INDX(1)      $     L2 = INDX(2)                              TRNSCO
      HSP = XFRACS(1) * HSHELL(L1) + (1.-XFRACS(1)) * HSHELL(L2)        TRNSCO
      CALL AEROSOL ( HSP, WAVEL, XKSCA, XKABS, GBAR )                   TRNSCO
CLJ        XKEXTP IS THE AEROSOL EXTINCTION COEFFICIENT AT POINT P, 1/CM TRNSCO
      XKEXTP = XKSCA + XKABS                                            TRNSCO
      DO 50 I=1,NC                                                      TRNSCO
      IF ( DS(I+1) .LE. 0. )  GO TO 60                                  TRNSCO
      L1 = INDX(I)                                                      TRNSCO
      L2 = INDX(I+1)                                                    TRNSCO
CLJ        GET THE ALTITUDE AT POINT Q ALONG THE TRANSMITTANCE PATH.    TRNSCO
      HSQ = XFRACS(I+1) * HSHELL(L2) + ( 1. - XFRACS(I+1) ) * HSHELL(L1) TRNSCO
      CALL AEROSOL ( HSQ, WAVEL, XKSCA, XKABS, GBAR )                   TRNSCO
CLJ        XKEXTQ IS THE AEROSOL EXTINCTION COEFFICIENT AT POINT Q, 1/CM TRNSCO
      XKEXTQ = XKSCA + XKABS                                            TRNSCO
CLJ        FIND THE MEAN AEROSOL EXTINCTION COEFFICIENT OVER THE PATH   TRNSCO
CLJ        ELEMENT DS(I+1) BY INTEGRATING THE LOGARITHMICALLY-          TRNSCO
CLJ        INTERPOLATED VALUE OF THE EXTINCTION COEFFICIENT OVER DS(I+1) TRNSCO
CLJ        AND DIVIDING BY DS(I+1).                                     TRNSCO
      XKEXT = ACCUM( 2, 0., DS(I+1), XKEXTP, XKEXTQ, 0., DS(I+1) ) /    TRNSCO
     *        DS(I+1)                                                   TRNSCO
CLJ        TDST IS THE AEROSOL TRANSMITTANCE FROM THE START OF THE PATH TRNSCO
CLJ        TO THE BACK OF ELEMENT DS(I+1)                               TRNSCO
      TDST = TDST * EXP( -XKEXT * DS(I+1) )                             TRNSCO
CLJ        RESET EXTINCTION COEFFICIENT OF NEW POINT P TO THAT AT THE   TRNSCO
CLJ        OLD POINT Q.                                                 TRNSCO
      XKEXTP = XKEXTQ                                                   TRNSCO
   50 CONTINUE                                                          TRNSCO
CLJ        TRANS BI(J) IS NOW RESET TO BE THE PRODUCT OF THE MOLECULAR  TRNSCO
CLJ        TRANSMITTANCE FOR ALL THE SPECIES AND THE AEROSOL            TRNSCO
CLJ        TRANSMITTANCE, EACH FOR THE ENTIRE PATH.                     TRNSCO
   60 TRANS BI(J) = TRANS BI(J) * TDST                                  TRNSCO
CLJ        PRESERVE THE AEROSOL TRANSMITTANCE BY SETTING IDSBX BI(J).   TRNSCO
      CALL XMIT (1,TDST,IDSBX BI(J))                                    TRNSCO
      GO TO 40                                                          TRNSCO
      END                                                               TRNSCO
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      SUBROUTINE UNITV ( VX, VXHAT )                                    UNITV
CLJ                                                                     UNIT"
CLJ      SUBROUTINE UNITV RETURNS THE UNIT VECTOR VXHAT(1-3) ALONG      UNITV
CLJ      THE VECTOR VX(1-3).                                            UNITV
CLJ                                                                     UNITV
      DIMENSION VX(3), VXHAT(3)                                         UNITV
      CALL VLIN ( VXHAT, 1./SQRT(DOT(VX,VX)), VX, O. , O. )             UNITV
      RETURN                                                            UNITV
      END                                                               UNITV
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      SUBROUTINE UPWELL ( MSM,DD,WW,DW,SPCULR,LBINT,JBAND )             UPWELL
CCC                                                                     UPWELL
C        SUBROUTINE UPWELL, FOR A POINT V AT EACH OF A SET OF NALTJ     UPWELL
C        ALTITUDES ABOVE A GIVEN GEOGRAPHIC POSITION, SPECIFIED IN      UPWELL
C        UPWELS COMMON (UPWLAT,UPWLON,UPWALT) AND CHARACTERIZED BY      UPWELL
C        MATERIAL MSM AND PROPERTY DD(MSM), COMPUTES THE NATURAL        UPWELL
C        UPWELLING SPECTRAL RADIANCE DIRECTED TOWARD POINT V FROM       UPWELL
C        POINTS P LOCATED ON THE EARTH'S SURFACE WITH RESPECT TO POINT  UPWELL
C        V AT NNADIR REPRESENTATIVE NADIR ANGLES AND NAZI REPRESENTA-   UPWELL
C        TIVE AZIMUTH ANGLES. THIS UPWELLING RADIANCE, UPRAD(I,J,K,L),  UPWELL
C        INCLUDES CONTRIBUTIONS FROM (1) AIR EMISSION BETWEEN POINTS    UPWELL
C        V AND P, (2) SURFACE EMISSION AT POINT P, AND (3) SURFACE-     UPWELL
C        REFLECTED SOLAR RADIATION AT EACH POINT P.  VALUES OF THE      UPWELL
C        RADIANCE UPRAD(I,J,K,L) ARE AVERAGED OVER AZIMUTH ANGLES TO    UPWELL
C        GIVE UPRADA(I,J,L) AND OVER NADIR ANGLES TO GIVE               UPWELL
C        UPRADN(I,L,JBAND).                                             UPWELL
C        *** NOTE ***    SEE COMMENTS GIVEN UNDER OUTPUT PARAMETERS FOR UPWELL
C        ***      ***    THE DIFFERENT MEANING OF UPRADN(I,L,JBAND) IN  UPWELL
C        ***      ***    THE GRC AND SAI VERSIONS.                      UPWELL
CCC                                                                     UPWELL
C        THE INCLUSION OF NATURAL CLOUDS COMPLICATES THE MODELING.  NO  UPWELL
C        ATTEMPT IS MADE TO INCLUDE THE DETERMINISTIC CLOUD SUBMODEL.   UPWELL
C        THE STATISTICAL CLOUD SUBMODEL IS INCLUDED ONLY FOR ALTITUDES  UPWELL
C        ZKM EQUAL TO OR GREATER THAN THE HIGHEST ALTITUDE (12 KM) OF A UPWELL
C        CLOUD IN THAT SUBMODEL.  THE GENERAL PROCEDURE IS TO FIRST     UPWELL
C        CONSIDER A GIVEN ALTITUDE, NADIR, AND AZIMUTH.  WITH THE AIR   UPWELL
C        EMISSION, ARCVA(IKM,J,L), ALONG THE LINE-OF-SIGHT (LOS) ABOVE  UPWELL
C        12-KM ALTITUDE SERVING AS A BASE VALUE, WE OBTAIN A            UPWELL
C        DISTRIBUTION FUNCTION FOR THE ADDITIONAL RADIANCE              UPWELL
C        CORRESPONDING TO CLOUD-FREE- AND CLOUDY-LOS EXTENDING BELOW    UPWELL
C        12-KM ALTITUDE.  BECAUSE THERE ARE 159 CLOUD CONFIGURATIONS IN UPWELL
C        THE STATISTICAL CLOUD MODEL, THIS DISTRIBUTION FUNCTION HAS    UPWELL
C        160 MEMBERS FOR NIGHTTIME AND 161 MEMBERS FOR DAYTIME...       UPWELL
C             159 FOR CLOUD-TOP EMISSION AND (IF DAYTIME)               UPWELL
C                 CLOUD-REFLECTED SOLAR RADIATION                       UPWELL
C               1 FOR EARTH'S SURFACE EMISSION AND AIR EMISSION BELOW   UPWELL
C                 12-KM ALTITUDE (FOR A 1-LEG CLOUD-FREE LOS)           UPWELL
C               1 FOR EARTH'S SURFACE EMISSION, AIR EMISSION BELOW 12-  UPWELL
C                 KM ALTITUDE, AND (IF DAYTIME) GROUND-REFLECTED SOLAR  UPWELL
C                 RADIATION (FOR A 2-LEG CLOUD-FREE LOS, OBTAINING IN   UPWELL
C                 DAYTIME)                                              UPWELL
C        THE LAST TWO MEMBERS ARE THE WEIGHTED CONTRIBUTIONS FOR CLOUD- UPWELL
C        FREE-LOS CONDITIONS.  (OWING TO CERTAIN SIMPLICATIONS MADE     UPWELL
C        IN THE CLOUD MODELING, THERE ARE ACTUALLY ONLY 9 AND NOT 159   UPWELL
C        DISTINCT VALUES IN THE DISTRIBUTION FOR A CLOUDY-LOS.)  HAVING UPWELL
C        DETERMINED THE DISTRIBUTION FUNCTION FOR A GIVEN LOOK          UPWELL
C        DIRECTION FROM POINT V, WE FORM THE                            UPWELL
C        INTEGRAL DISTRIBUTION AND COMPUTE SELECTED PERCENTILES (XXX=   UPWELL
C        10,25,50,90,100) OF THE INTEGRAL DISTRIBUTION, RXXX(K,L), AT   UPWELL
C        IMPLICIT ALT.-IKM, IMPLICIT NADIR-J, AND EXPLICIT AZIMUTH-K.   UPWELL
C        VALUES OF RXXX(K,L) ARE AVERAGED OVER AZIMUTH ANGLES TO GIVE   UPWELL
C        RXXXA(IKM,J,L).  VALUES OF ARCVA(IKM,J,L) AND RXXXA(IKM,J,L)   UPWELL
C        ARE AVERAGED OVER NADIR ANGLES TO GIVE ARCVN(IKM,L) AND        UPWELL
C        RXXXN(IKM,L), RESPECTIVELY.                                    UPWELL
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C
C         *** NOTE ***   SINCE THE INCLUSION OF THE INDEX JBAND WAS A
C         LATE CHANGE (MARCH 1980), WE ELECTED NOT TO MODIFY THE ARRAYS
C         ARCVN(IKM,L) AND RXXXN(IKM,L) TO PROVIDE FOR AN EXPLICIT
C         DEPENDENCE ON THE INDEX JBAND AS WE DID FOR THE ARRAY UPRADN(I
C         ,L,JBAND).  THIS LIMITATION MUST BE REMEMBERED AND REMOVED IF
C         JBAND.GT.1 AND IF CLOUDS ARE INCLUDED, UNLESS ONE IS CONTENT
C         TO ADOPT THE GRC DEFINITION OF UPRADN(I,L,JBAND).
C
C         NOTE THAT IT WOULD PROBABLY BE MORE CONCEPTUALLY SATISFYING IF
C         ONE COULD PERFORM AZIMUTH- AND NADIR-AVERAGES FOR EACH OF THE
C         CLOUD CONFIGURATIONS, SO THAT ONE COULD END UP WITH A
C         DISTRIBUTION FUNCTION AT A GIVEN ALTITUDE INSTEAD OF AVERAGED
C         PERCENTILE-VALUES.  SUCH A PROCEDURE WAS NOT FOLLOWED.
C
C         NOTE THAT THE NATURAL CLOUD MODEL DOES NOT INCLUDE AIR
C         EMISSION BETWEEN CLOUD TOPS AND 12-KM ALTITUDE.  HENCE, SUCH
C         AIR EMISSION IS NOT INCLUDED HERE, EITHER.
CCC
CC        THE UPWELLING NATURAL RADIATION MODEL (23C) HAS NOW BEEN
CC        INTEGRATED WITH THE FOLLOWING MODELS....
CC           AMBIENT ATMOSPHERE                 1A          SAI/LJ
CC           ATMOSPHERIC AEROSOLS               1C,19.1C    VI
CC           NATURAL CLOUDS                     1D,19.1D    SAI/PA
CC           ATMOSPHERIC THERMAL EMISSION       20B         GET
CC           EARTH SURFACE CHARACTERIZATION     23A         SAI/LJ
CC           EARTH SURFACE RADIANCE             23B         SAI/LJ
CC           SOLAR RADIATION                    23E         SAI/LJ
CC           MOLECULAR TRANSMITTANCE            24D         GET
CCC
C         INPUT PARAMETERS
C            ARGUMENT LIST
C                  MSM - INDEX FOR CATEGORY OF SURFACE MATERIAL (SEE
C                        SUBROUTINE ESURF FOR DEFINITIONS)
C                   DD - ADDITIONAL DESCRIPTOR FOR SELECTED SURFACE
C                        MATERIAL (SEE SUBROUTINE ESURF FOR DEFINITIONS)
C                   WW - ARRAY OF CENTRAL WAVENUMBERS,  CM-1
C                   DW - ARRAY OF WAVENUMBER-INTERVAL WIDTHS,  CM-1
C               SPCULR - LOGICAL PARAMETER
C                      = .TRUE.  COMPUTE COORDINATES OF SPECULAR
C                                REFLECTION POINT ON A SMOOTH
C                                HORIZONTAL WATER SURFACE.
C                      = .FALSE. DO NOT COMPUTE COORDINATES OF SPECULAR
C                                REFLECTION POINT.
C                LBINT - WORD NO. 5 (LHV) IN GRC DATASET-BN (NO. 114),
C                        LIST OF BAND-INTERVAL DATASETS (BI).
C                        STRICTLY, LBINT IS THE POINTER (I.E., CONTAINS
C                        THE (Q-ARRAY) ADDRESS) FOR THE LIST HEADER OF
C                        THE BAND-INTERVAL DATASETS-BI CORRESPONDING TO
C                        DATASET-BN.
C                JBAND - INDEX FOR LIST OF (BROAD) WAVELENGTH BANDS
C            AIRSOL COMMON
C              TASP(L) - AEROSOL TRANSMITTANCE FOR INCOMING SOLAR RAY TO
C                        POINT P ON GROUND.  L=1,NWAVEJ
C              TASC(L) - AEROSOL TRANSMITTANCE FOR INCOMING SOLAR RAY TO
C                        POINT C AT 12-KM ALTITUDE.  L=1,NWAVEJ
C            OPTIN1 COMMON
C                RADSW - LOGICAL PARAMETER.  IS AN INITIALIZATION SWITCH
C                        FOR ATMOSPHERIC VOLUME EMISSION CALCULATION.
C                        IS SET IN INPUT TO (DRIVER) PROGRAM DRVUPW FOR
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C                   SUBROUTINE UPWELL.                              UPWELL
C                 = .TRUE. , INCLUDE CALL (FROM SUBROUTINE TRNSCO)  UPWELL
C                            TO SUBROUTINE ATMRAD                   UPWELL
C                 = .FALSE., BYPASS CALL TO SUBROUTINE ATMRAD AND   UPWELL
C                            PERFORM TRANSMITTANCE CALCULATION      UPWELL
C                            WITHOUT INCLUDING AIR EMISSION.        UPWELL
C         OPTION COMMON                                             UPWELL
C           TRNSOPT - LOGICAL VARIABLE AFFECTING COMPLEXITY OF      UPWELL
C                     MOLECULAR TRANSMITTANCE CALCULATION (SEE      UPWELL
C                     SUBROUTINES TRANSB AND TRANS).  IN SUBROUTINE UPWELL
C                     UPWELL, TRNSOPT IS USED ONLY IN THE ARGUMENT  UPWELL
C                     LIST FOR CALLS TO SUBROUTINE TRANS.           UPWELL
C         SOLARP COMMON                                             UPWELL
C            SOLLAT - SUBSOLAR POINT NORTH LATITUDE,  RADIANS       UPWELL
C            SOLLON - SUBSOLAR POINT EAST LONGITUDE,  RADIANS       UPWELL
C            SOLIRR(L)  (L=1,NWAVEJ)                                UPWELL
C                   - SOLAR SPECTRAL IRRADIANCE AT THE TOP OF THE   UPWELL
C                     EARTH'S ATMOSPHERE AT WAVENUMBER-INDEX L      UPWELL
C                     WATTS / ( CM**2 CM-1 )                        UPWELL
C         UPWELS COMMON                                             UPWELL
C            UPWLAT - NORTH LATITUDE OF POINT V AT WHICH UPWELLING  UPWELL
C                     RADIANCE IS COMPUTED,  RADIANS                UPWELL
C            UPWLON - EAST LONGITUDE OF POINT V AT WHICH UPWELLING  UPWELL
C                     RADIANCE IS COMPUTED,  RADIANS                UPWELL
C            UPWALT - SURFACE ALTITUDE OF THE SUB-V-POINT,  KM      UPWELL
C            NALT(JBAND)  (JBAND=1,NBANDS)                          UPWELL
C                   - NUMBER OF ALTITUDES ZKM FOR (BROAD) WAVELENGTH- UPWELL
C                     BAND INDEX JBAND.  DEFINES NALTJ.             UPWELL
C            ZKM(I,JBAND)  (I=1,NALTJ,  JBAND=1,NBANDS)             UPWELL
C                   - ALTITUDES OF POINT V ABOVE UPWALT AT WHICH    UPWELL
C                     UPWELLING RADIANCE IS COMPUTED,  KM           UPWELL
C            NNADIR - NUMBER OF NADIR ANGLES AT POINT V AT WHICH    UPWELL
C                     UPWELLING RADIANCE IS COMPUTED                UPWELL
C              NAZI - NUMBER OF AZIMUTH ANGLES AT POINT V AT WHICH  UPWELL
C                     UPWELLING RADIANCE IS COMPUTED                UPWELL
C            NWAVE(JBAND)  (JBAND=1,NBANDS)                         UPWELL
C                   - NUMBER OF WAVENUMBERS AT WHICH THE UPWELLING  UPWELL
C                     SPECTRAL RADIANCE IS TO BE COMPUTED FOR (BROAD) UPWELL
C                     WAVELENGTH-BAND INDEX JBAND.  DEFINES NWAVEJ. UPWELL
CC          CLDFLG - INDEX FOR INCLUSION OF NATURAL CLOUDS          UPWELL
CC                 = 0. IF NATURAL CLOUDS ARE NOT INCLUDED          UPWELL
CC                 = 1. IF NATURAL CLOUDS ARE INCLUDED              UPWELL
CC      CLDFREQ COMMON                                              UPWELL
CC          KMODEL - INDEX (1,11) CHARACTERIZING A SET OF STATISTICAL UPWELL
CC                   AVERAGES OF CLOUD COVERAGE CATEGORIES, CLOUD   UPWELL
CC                   TYPES, AND NUMBER OF CLOUD LAYERS FOR A GIVEN  UPWELL
CC                   GEOGRAPHIC REGION.  CHARACTERIZES A SPECIFICATION UPWELL
CC                   OF CCOVER(5,11) AND CFREQ(17,4,11) IN BLOCK DATA UPWELL
CC                   FOR KMODEL=1,10.  USER MUST SUPPLY HIS OWN DATA UPWELL
CC                   FOR KMODEL=11.                                 UPWELL
CC          CCOVER(ICC,KMODEL) ((ICC=1,5),KMODEL=1,11)              UPWELL
CC                 - FRACTIONAL OCCURRENCE FREQUENCY OF CLOUD COVERAGE UPWELL
CC                   CATEGORY ICC FOR GIVEN KMODEL                  UPWELL
CC      CLDWT COMMON                                                UPWELL
CC            IDX - INDEX FOR LENGTH OF ARRAYS RETURNED FROM        UPWELL
CC                  SUBROUTINE CLDWT.  IDX EQUALS 160 FOR A FULL SET UPWELL
CC                  OF 159 CLOUD-LAYER AND CLOUD-TYPE CONFIGURATIONS UPWELL
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CC              AND IS LESS FOR A RESTRICTED SET.                    UPWELL
CC         WT(I) - PROBABILITY OF CONFIGURATION-I.  IDX EQUALING 160 UPWELL
CC         I=1,IDX  CORRESPONDS TO A CLOUD-FREE LINE-OF-SIGHT.       UPWELL
CC      TRANS(I) - TRANSFER COEFFICIENT FOR CONFIGURATION-I.  IN NBR UPWELL
CC      I=1,IDX-1  MODULE, GEOMETRY FOR TRANSMISSION THROUGH CLOUDS  UPWELL
CC              IS NOT INCLUDED.  ONLY GEOMETRY FOR REFLECTION OF    UPWELL
CC              SOLAR RAY FROM THE HIGHEST-LAYER CLOUD IN            UPWELL
CC              CONFIGURATION-I IS INCLUDED.  ATTENUATION IS         UPWELL
CC              INCLUDED (WITHIN THE NATURAL CLOUD MODEL) TO 12-     UPWELL
CC              KM ALTITUDE.  (1/SR)                                 UPWELL
CC      EMISS(I) - THERMAL SPECTRAL RADIANCE FROM THE HIGHEST-LAYER  UPWELL
CC      I=1,IDX-1  CLOUD IN CONFIGURATION-I WITH ATTENUATION COMPUTED UPWELL
CC              (WITHIN THE NATURAL CLOUD MODEL) TO 12-KM ALTITUDE UPWELL
CC              (W/(KM**2 SR MICRON))                                UPWELL
C     QNCNC COMMON                                                   UPWELL
C         NCNC - A VARIABLE, SET TO NC AFTER THE DOUBLE CALL TO      UPWELL
C               SUBROUTINE STEPS IN SUBROUTINE TRNSCO, EMPLOYED TO UPWELL
C               FACILITATE BEING ABLE TO USE ZERO-KILOMETER          UPWELL
C               ALTITUDE IN THE NBR MODULE.  FOR MORE INFORMATION, UPWELL
C               SEE COMMENTS PRECEDING LABEL NUMBER 22.              UPWELL
C     OUTPUT PARAMETERS                                              UPWELL
C        *** NOTE ***    UPRAD(K,L), UPRADA(I,J,L), AND UPRADN(I,L,  UPWELL
C           JBAND) ARE CLOUD-FREE RESULTS.  FOR RESULTS WHICH ALSO  UPWELL
C           INCLUDE CLOUD EFFECTS FOR ALTITUDES .GE. 12 KM,          UPWELL
C           USE THE CORRESPONDING ARRAYS RXXX(K,L), RXXXA(IKM,J,L), UPWELL
C           AND RXXXN(IKM,L).  TO THESE ARRAYS ONE MUST ADD,         UPWELL
C           RESPECTIVELY, THE BASE-VALUE QUANTITIES ARCVA(IKM,J,L), UPWELL
C           ARCVA(IKM,J,L), AND ARCVN(IKM,L).                        UPWELL
C        *** NOTE ***    IN THE GRC VERSION, FOR ALTITUDES EQUAL TO  UPWELL
C           OR GREATER THAN 12 KM AND IF CLOUDS ARE INCLUDED, THE   UPWELL
C           ARRAY UPRADN(I,L,JBAND) IS RESET AS                      UPWELL
C              UPRADN(I,L,JBAND) = RO50N(IKM,L) + ARCVN(IKM,L) ,     UPWELL
C           WHICH IS TRANSFERRED THROUGH UPWELS COMMON TO (THE GRC) UPWELL
C           SUBROUTINE UPWELT.  THUS, IN THE GRC VERSION, FOR        UPWELL
C           ALTITUDES ZKM.GE.12-KM, UPRADN IS NOT THE CLOUD-FREE     UPWELL
C           RESULT BUT THE 50-PERCENTILE OF THE RADIANCE             UPWELL
C           DISTRIBUTION FUNCTION FOR STATISTICAL CLOUDS (IF         UPWELL
C           INCLUDED IN THE PROBLEM).                                UPWELL
C        UPWELS3 COMMON                                              UPWELL
C        UPRAD(K,L)  K=1,NAZI,  L=1,NWAVEJ                           UPWELL
C                  (IMPLICITLY I=1,NALTJ, J=1,NNADIR)                UPWELL
C                  (I- AND J-DEPENDENCE IS NOT STORED, SO USER       UPWELL
C                  MUST PRINT UPRAD(K,L) IMMEDIATELY AFTER           UPWELL
C                  COMPUTATION IF HE WANTS TO SEE THEM).             UPWELL
C                  CURRENTLY, UPRAD(K,L) AND RXXX(K,L) ARE BEING     UPWELL
C                  WRITTEN IN BINARY FORM ON LOGICAL UNIT NO. 8,     UPWELL
C                  FOR ALL APPROPRIATE ALTITUDES AND NADIRS.         UPWELL
C                - NATURAL UPWELLING SPECTRAL RADIANCE RECEIVED      UPWELL
C                  AT POINT V (AT ALTITUDE-I ABOVE SURFACE MAT'RL    UPWELL
C                  MSM) ALONG A RAY DIRECTED TO POINT P ON           UPWELL
C                  EARTH'S SURFACE (AT NADIR-J AND AZIMUTH-K),       UPWELL
C                  WATTS/(CM**2 SR CM-1)                             UPWELL
C        UPRADA(I,J,L)  I=1,NALTJ,  J=1,NNADIR,  L=1,NWAVEJ          UPWELL
C                - THE AZIMUTH-AVERAGED VALUE OF UPRAD(K,L),         UPWELL
C                  WATTS/(CM**2 SR CM-1)                             UPWELL
C        SORCE COMMON (SOLAR COORDINATES ARE NEEDED IN SUBROUTINE    UPWELL
C                   TRANSF OF THE NATURAL CLOUD MODULE.)             UPWELL
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C          NSORCE - NUMBER OF SOURCES.  SET TO 1 IN DATA STATEMENT. UPWELL
C          HSORCE(1) - ALTITUDE OF SUN (RSUN).  RSUN SET IN DATA     UPWELL
C                      STATEMENT.                                    UPWELL
C          RSORCE(1) - RADIUS OF SOURCE.  TRUE VALUE FOR SUN IS NOT UPWELL
C                      RELEVANT FOR THIS APPLICATION IN NATURAL      UPWELL
C                      BACKGROUND RADIATION MODULE.  SET TO 0.0 IN  UPWELL
C                      DATA STATEMENT.                               UPWELL
C          THETAS - COLATITUDE OF SUBSOLAR POINT, DEGREES            UPWELL
C          PHIS   - EAST LONGITUDE OF SUBSOLAR POINT, DEGREES        UPWELL
C       TECTOR COMMON (USED HERE TO POSITION FICTITIOUS DETECTOR     UPWELL
C                      AT POINT V)                                   UPWELL
C          DETLAT - DETECTOR NORTH LATITUDE,  RADIANS                UPWELL
C          DETLON - DETECTOR EAST LONGITUDE,  RADIANS                UPWELL
C          DETALT - DETECTOR ALTITUDE,  KM                           UPWELL
C       POSITN COMMON                                                UPWELL
C          POSLAT - NORTH LATITUDE OF POINT P AT WHICH LINE-OF-      UPWELL
C                   SIGHT INTERSECTS EARTH'S SURFACE,  RADIANS       UPWELL
C          POSLON - EAST LONGITUDE OF POINT P AT WHICH LINE-OF-      UPWELL
C                   SIGHT INTERSECTS EARTH'S SURFACE,  RADIANS       UPWELL
C          POSALT - ALTITUDE OF POINT P AT WHICH LINE-OF-SIGHT       UPWELL
C                   INTERSECTS EARTH'S SURFACE,  KM                  UPWELL
C          C12LAT - NORTH LATITUDE OF POINT C AT WHICH LINE-OF-      UPWELL
C                   SIGHT INTERSECTS THE 12-KM ALTITUDE SURFACE,     UPWELL
C                   RADIANS                                          UPWELL
C          C12LON - EAST LONGITUDE OF POINT C AT WHICH LINE-OF-      UPWELL
C                   SIGHT INTERSECTS THE 12-KM ALTITUDE SURFACE,     UPWELL
C                   RADIANS                                          UPWELL
C          C12ALT - ALTITUDE OF POINT C AT WHICH LINE-OF-SIGHT       UPWELL
C                   INTERSECTS 12-KM ALTITUDE SURFACE, KM            UPWELL
C       UPWELS COMMON                                                UPWELL
C            IDAYV - INDEX FOR DAYLIGHT CONDITION AT SUB-V-POINT     UPWELL
C                  = 0  IF SOLAR ZENITH ANGLE .GT. 90 DEGREES        UPWELL
C                  = 1  IF SOLAR ZENITH ANGLE .LE. 90 DEGREES        UPWELL
C          UPRADN(I,L,JBAND)  I=1,NALTJ, L=1,NWAVEJ, JBAND=1,NBANDS UPWELL
C                 - THE NADIR-AVERAGED VALUE OF UPRADA(I,J,L),       UPWELL
C                   WATTS/(CM**2 SR CM-1)                            UPWELL
C              IKM - INDEX FOR NUMBER OF ALTITUDES AT WHICH          UPWELL
C                   CALCULATIONS ARE MADE WHEN CLOUDS ARE INCLUDED. UPWELL
C                   (USED IN SUBROUTINE SURRAD)                      UPWELL
C       UPWELS1 COMMON                                               UPWELL
C       ARCVA(IKM,J,L) FOR IKM.GE.1,            J=1,NNADIR,          UPWELL
C                                               L=1,NWAVEJ           UPWELL
C               - WHEN CLOUDS ARE CONSIDERED, A COMPONENT OF THE     UPWELL
C                 UPWELLING SPECTRAL RADIANCE RECEIVED AT POINT V    UPWELL
C                 (AT ALTITUDE-IKM), FROM AIR EMISSION ABOVE 12-KM   UPWELL
C                 ALTITUDE, ALONG A RAY DIRECTED TO POINT P ON THE   UPWELL
C                 EARTH SURFACE (AT NADIR-J AND INDEPENDENT OF       UPWELL
C                 AZIMUTH-K),  WATTS/(CM**2 SR CM-1)                 UPWELL
C       ARCVN(IKM,L) FOR IKM.GE.1, L=1,NWAVEJ                        UPWELL
C               - THE NADIR-AVERAGED VALUE OF ARCVA(IKM,J,L),        UPWELL
C                              WATTS/(CM**2 SR CM-1)                 UPWELL
C       RXXX(K,L)     (XXX=10,25,50,90,100)                          UPWELL
C               - XXX PERCENTILE OF THE INTEGRAL DISTRIBUTION OF THE UPWELL
C                 TOTAL (INCLUDING THAT FROM STATISTICAL CLOUDS)     UPWELL
C                 NATURAL UPWELLING SPECTRAL RADIANCE RECEIVED AT    UPWELL
C                 POINT V FOR WAVENUMBER-L (AT IMPLICIT ALTITUDE-IKM UPWELL
C                 ABOVE SURFACE MATERIAL MSM) ALONG A RAY DIRECTED   UPWELL
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C                    TO POINT P ON EARTH SURFACE (AT IMPLICIT NADIR-J
C                    AND EXPLICIT AZIMUTH-K), WATTS/(CM**2 SR CM-1)
C                  **NOTE THAT RXXX(K,L) DOES NOT INCLUDE
C                       ARCVA(IKM,J,L).
C                       CURRENTLY, UPRAD(K,L) AND RXXX(K,L) ARE BEING
C                       WRITTEN IN BINARY FORM ON LOGICAL UNIT NO. 8,
C                       FOR ALL APPROPRIATE ALTITUDES AND NADIRS.
C            RXXXA(IKM,J,L)    (XXX=10,25,50,90,100)
C                  - THE AZIMUTH-AVERAGED VALUE OF RXXX(K,L),
C                            WATTS/(CM**2 SR CM-1)
C            RXXXN(IKM,L)    (XXX=10,25,50,90,100)
C                  - THE NADIR-AVERAGED VALUE OF RXXXA(IKM,J,L),
C                            WATTS/(CM**2 SR CM-1)
C            FLAGS COMMON
C            ITFLAG - FLAG INDICATING THE DIURNAL CONDITION AT POINT V',
C                    FOR USE BY SUBROUTINE CLDWT IN THE NATURAL CLOUD
C                    MODULE.
C                    = 0, SUN IS BELOW THE HORIZON
C                    = 1, SUN IS ABOVE THE HORIZON
C            SANDD COMMON
C               XS, - EARTH-CENTERED CARTESIAN COORDINATES OF THE SUN.
C               YS,       (KM)
C               ZS
C               XD, - EARTH-CENTERED CARTESIAN COORDINATES OF THE
C               YD,    FICTITIOUS DETECTOR AT POINT V.
C               ZD        (KM)
C               UL, - DIRECTION COSINES OF POINT P FROM POINT V.
C               VL,
C               WL
C            UPWELS2 COMMON
C            JBAND1 - SAME AS JBAND, BUT MADE AVAILABLE TO SUBROUTINE
C                    SURRAD TO FACILITATE PRINT.
CCC
      COMMON  QBLNKQ(89), Q(1)
      EQUIVALENCE  (Q,IQ)
      DIMENSION IQ(1)
      DIMENSION BNLO  BI(1), BNHI  BI(1), WLO   BI(1), WHI   BI(1),
     *          BKGND BI(1), TFLAG BI(1), TRANS BI(1), IDSBX BI(1)
C           *** SEE SUBROUTINE ATMRAD FOR DEFINITIONS OF DATASET BI
      EQUIVALENCE ( Q(1), BNLO  BI ), ( Q(2), BNHI  BI ),
     *            ( Q(3), WLO   BI ), ( Q(4), WHI   BI ),
     *            ( Q(5), BKGND BI ), ( Q(6), TFLAG BI ),
     *            ( Q(7), TRANS BI ), ( Q(8), IDSBX BI )
      DIMENSION  RP(3),RC(3),RV(3),TAU(10),OMEGAT(13),WW(10),DW(10)
      DIMENSION  DD(7),RAD(12),UPS(10,10,11),UPPS(10,10,11),
     $                    UCS(10,10)   ,UPCS(10,10),
     $                    UPV(10,10)   ,UPPV(10,10),
     $                    UCV(10,10)   ,UPCV(10,10),
     $                   USPV(10,10)  ,UPSPV(10,10),
     $                   USCV(10,10)  ,UPSCV(10,10)
      DIMENSION  TAPV(10),TTPV(10),TTSPV(10),TMSPV(10),AEPV(10)
      DIMENSION  TACV(10),TTCV(10),TTSCV(10),TMSCV(10),AECV(10)
      DIMENSION  ABC(10)
      DIMENSION  WTC(162),UPRADC(162),UPRDC1(162)
      COMMON/OPTION/  TRNSOPT
      COMMON / OPTIN1 / RADSW
      COMMON/ QNCNC/  NCNC
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      COMMON/AIRSOL/  TASP(10),TASC(10),TAFP(10)                        AIRSOL     2
      COMMON/CLDFREQ/  KMODEL,CCOVER(5,11),CFREQ(17,4,11)               CLDFREQ    2
      COMMON/CLDWT/  IDX,WT(161),TRANS(161),EMISS(161)                  CLDBUG     1
      COMMON/POSITN/  POSLAT,POSLON,POSALT,SPCLAT,SPCLON                POSITN     2
     :               ,C12LAT.C12LON,C12ALT                              POSITN     3
      COMMON /SANDD/ XS,YS,ZS,XD,YD,ZD,UL,VL,WL                         SANDDQ     2
C     SAI'S /SORCE/ DIFFERS FROM GRC'S.                                 24APR80    2
      COMMON/ SORCE/  NSORCE,HSORCE(1),RSORCE(1),THETAS,PHIS            KOMATM     1
      COMMON/SOLARP/  SOLLAT,SOLLON,SOLIRR(10)                          SOLARP     2
      COMMON/TECTOR/  DETLAT,DETLON,DETALT,DETZEN,DETAZI(11)            TECTOR     2
      COMMON/UPWELS/ UPWALT,UPWLON,UPWLAT,NALT(5),ZKM(13,5),NNADIR,NAZI, UPWELS    2
     *               NWAVE(5),IDAYV,CLDFLG,UPRADN(13,10,5),WV(10,5),IKM, UPWELS    3
     *               NBANDS                                             UPWELS     4
      COMMON/UPWELS1/                                                   UPWELS     5
     2               R010(6,10),R010A(6,10,10),R010N(6,10),             UPWELS     6
     3               R025(6,10),R025A(6,10,10),R025N(6,10),             UPWELS     7
     4               R050(6,10),R050A(6,10,10),R050N(6,10),             UPWELS     8
     5               R090(6,10),R090A(6,10,10),R090N(6,10),             UPWELS     9
     6               R100(6,10),R100A(6,10,10),R100N(6,10)              UPWELS    10
     7                          ,ARCVA(6,10,10),ARCVN(6,10)             UPWELS    11
      COMMON/UPWELS2/ JBAND1                                            XYZCOM     2
      COMMON/UPWELS3/ UPRAD(6,10),UPRADA(13,10,10)                      XYZCOM     3
      COMMON/ XYZCOM/ ITMTE,LTMTE,NS,HSHELL(81),TPX(81,12),             XYZCOM     4
     1                U(10,10,2),UP(10,10,2),NMOLS,FACT                 XYZCOM     5
C     SAI'S /FLAGS/ DIFFERS FROM GRC'S.                                 24APR80    1
      COMMON/ FLAGS/  ITFLAG                                            FLAGS      2
      LOGICAL  SPCULR,SPCLRX,RADSW,TRNSOPT                              UPWELL   356
      DATA  PI,RE / 3.14159265359O,6.37103E+03 /                        UPWELL   357
      DATA  NSPECS,NTEMP / 10,10 /                                      UPWELL   358
      DATA  NSORCE, RSORCE(1) / 1, 0.0 /                                UPWELL   359
      DATA  RSUN / 1.495979E+08 /                                       UPWELL   360
CCC                                                                     UPWELL   361
CC    SET JBAND1 IN COMMON /UPWELS2/ TO FACILITATE SOME PRINT IN        UPWELL   362
CC    SUBROUTINE SURRAD.                                                UPWELL   363
      JBAND1 = JBAND                                                    UPWELL   364
CCC                                                                     UPWELL   365
CC    SET VARIABLES IN TECTOR COMMON FOR INITIAL POSITION OF            UPWELL   366
CC    DETECTOR AT SUBPOINT V', FOR USE IN DETERMINING THE REFERENCE     UPWELL   367
CC    AZIMUTH ANGLE.                                                    UPWELL   368
      DETLAT = UPWLAT                                                   UPWELL   369
      DETLON = UPWLON                                                   UPWELL   370
      DETALT = UPWALT                                                   UPWELL   371
CC    SET REFERENCE AZIMUTH, REFAZI, TO BE THAT OF THE SUBSOLAR         UPWELL   372
CC    POINT WITH RESPECT TO POINT V IF SUN IS ABOVE THE HORIZON AT      UPWELL   373
CC    SUBPOINT V' OR ZERO OTHERWISE.                                    UPWELL   374
      PID2 = PI/2.                                                      UPWELL   375
      REFAZI = 0.0                                                      UPWELL   376
CC    IS SUN ABOVE THE HORIZON AT SUBPOINT V'?                          UPWELL   377
      SINSIN = SIN(DETLAT)*SIN(SOLLAT)                                  UPWELL   378
      COSCOS = COS(DETLAT)*COS(SOLLAT)                                  UPWELL   379
      CSSOLZ = SINSIN + COSCOS*COS(DETLON-SOLLON)                       UPWELL   380
      IDAYV = 0                                                         UPWELL   381
CC                                                                      UPWELL   382
CC    WHEN (A) CORE IS PRESET TO NON-ZEROS AND (B) SUN IS BELOW         UPWELL   383
CC    THE HORIZON, WE NEED TO SET THE SOLAR COORDINATES TO ARBITRARY    UPWELL   384
CC    VALUES SO THAT SUBROUTINE SGEOM (CALLED FROM EMISSF, CALLED       UPWELL   385
CC    FROM CLDWT, CALLED FROM UPWELL) WILL NOT ABORT IN TRYING TO       UPWELL   386
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CC        COMPUTE SOURCE GEOMETRY EVEN WHEN WE DON'T WANT IT.              UPWELL
      XS = 0.   $   YS = 0.   $   ZS = 0.                                  UPWELL
CC                                                                         UPWELL
      IF( CSSOLZ.LT.0.0 )  GO TO 10                                        UPWELL
      IDAYV = 1                                                            UPWELL
CC        DETERMINE AZIMUTH OF SUBPOINT S' OF SUN BY USING A MODIFIED      UPWELL
CC        HARC SUBROUTINE GEOREA. NOTE THAT GEOREA CALLS A HARC ROUTINE    UPWELL
CC        GEOXYZ WHICH WE HAVE RENAMED GEOTAN TO DISTINGUISH IT FROM       UPWELL
CC        THE SAI ROUTINE GEOXYZ.                                          UPWELL
      DALTCM = 1.0E+05*DETALT                                              UPWELL
      CALL GEOREA(DALTCM,PID2-DETLAT,DETLON,0.0,PID2-SOLLAT,SOLLON,        UPWELL
     $ SR21,EL21,REFAZI)                                                   UPWELL
CC        NOW HAVE REFAZI.  ALSO HAVE UNNEEDED SR21 AND EL21.              UPWELL
CC        GET EARTH-CENTERED CARTESIAN COORDINATES OF SUN FOR SGEOM.       UPWELL
      CALL GEOXYZ(RSUN,SOLLAT,SOLLON,XS,YS,ZS)                             UPWELL
CC        SET COORDINATES OF SUN INTO SORCE COMMON FOR TRANSF.             UPWELL
      HSORCE(1) = RSUN                                                     UPWELL
      THETAS = (PID2-SOLLAT)*180./PI                                       UPWELL
      PHIS = SOLLON*180./PI                                                UPWELL
CC                                                                         UPWELL
CC        ZERO ARRAYS USPV, UPSPV, USCV, AND UPSCV USED LATER TO           UPWELL
CC        PRESERVE PATH PARAMETERS FOR THE PATHS SPV AND SCV.              UPWELL
      CALL XMIT ( -100, 0., U SPV )                                        UPWELL
      CALL XMIT ( -100, 0., UPSPV )                                        UPWELL
      CALL XMIT ( -100, 0., U SCV )                                        UPWELL
      CALL XMIT ( -100, 0., UPSCV )                                        UPWELL
CC                                                                         UPWELL
   10 CONTINUE                                                             UPWELL
CC                                                                         UPWELL
CC        SET ALTITUDES OF ALL POINTS P (TO BE VIEWED FROM POINT V)        UPWELL
CC        EQUAL TO THE SURFACE ALTITUDE OF THE SUB-V-POINT.                UPWELL
      POSALT = UPWALT                                                      UPWELL
      PALTCM = 1.0E+05*POSALT                                              UPWELL
CC        IKM = INDEX FOR THE NUMBER OF ALTITUDES AT WHICH NATURAL         UPWELL
CC        CLOUDS HAVE BEEN INCLUDED IN THE UPWELLING RADIANCE              UPWELL
CC        CALCULATION (REQUIRED BECAUSE CLOUDS ARE INCLUDED ONLY FOR       UPWELL
CC        ALTITUDES ZKM EQUAL TO OR GREATER THAN 12. KM).                  UPWELL
      IKM = 0                                                              UPWELL
CC        BEGIN LOOP OVER NALTJ ALTITUDES.                                 UPWELL
      NALTJ = NALT(JBAND)                                                  UPWELL
      DO 80 I=1,NALTJ                                                      UPWELL
CC        IIP,JJP,KKP,LLP ARE THE LOOP INDICES USED IN THE CALL TO         UPWELL
CC        SUBROUTINE SURRAD WITHIN THE WAVENUMBER LOOP.                    UPWELL
      IIP = I                                                              UPWELL
      IF( ZKM(I,JBAND) .LT. 0.001 )  ZKM(I,JBAND) = 0.001                  UPWELL
      DETALT = UPWALT + ZKM(I,JBAND)                                       UPWELL
      DALTCM = 1.0E+05*DETALT                                              UPWELL
CC        GET EARTH-CENTERED CARTESIAN COORDINATES OF POINT V.             UPWELL
      CALL GEOXYZ(DETALT,DETLAT,DETLON,RV(1),RV(2),RV(3))                  UPWELL
CC        GET EARTH-CENTERED CARTESIAN COORDINATES OF DETECTOR FOR SGEOM UPWELL
      XD = RV(1)                                                           UPWELL
      YD = RV(2)                                                           UPWELL
      ZD = RV(3)                                                           UPWELL
      CALL VLIN(RV,1.0E+05,RV,0.0,0.0)                                     UPWELL
CC        FOR ALTITUDE DETALT, DETERMINE FRACTION OF 2*PI SOLID ANGLE,     UPWELL
CC        OMEGAT, THAT IS SUBTENDED BY THE TANGENT CONE WITH VERTEX AT     UPWELL
CC        POINT V.  FIRST, COMPUTE SLANT RANGE, SRT, OF TANGENT RAY        UPWELL
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CC        FROM POINT V.
      SRT = SQRT( (2.*RE+DETALT)*DETALT )
CC        COMPUTE COSINE OF NADIR ANGLE, CBETAT = COS(BETAT), CORRES-
CC        PONDING TO TANGENT RAY.
      CBETAT = SRT/(RE+DETALT)
      OMEGAT(I) = 1.0-CBETAT
CC        IT MAY NOT BE NECESSARY TO SAVE THESE SOLID ANGLE FACTORS.
CC        CLDFG1 - FLAG CONTROLLING A TEMPORARY ASPECT OF THE
CC                 CLOUD-RELATED CALCULATIONS.  CLDFG1 IS ALWAYS 0.0 IF
CC                 CLDFLG = 0.0 BUT MAY BE 0.0 OR 1.0 IF CLDFLG = 1.0 .
CC        CLDFG1 IS SET TO 0.0 JUST BEFORE THE TEST ON ALLOWED
CC        ALTITUDES AND MASTER FLAG (CLDFLG) FOR INCLUSION OF CLOUDS
CC        AND IS RESET TO 1.0 JUST AFTER THIS TEST.
CC        CLDFG1 CONTROLS THE CALCULATION OF (A) CFPV IN NADIR LOOP,
CC        SINCE CFPV IS INDEPENDENT OF AZIMUTH BUT DEPENDENT ON NADIR
CC        AND HENCE ALTITUDE, AND  (B) VARIOUS CLOUD-RELATED QUANTITIES
CC        IN WAVENUMBER LOOP.
CC              = 1.0 ALLOWS CALCULATION ON FIRST PASS.
CC              = 0.0 BYPASSES CALCULATION ON LATER PASSES OR
CC                    BYPASSES CALCULATION ON ALL PASSES IF CLDFLG=0.0.
      CLDFG1 = 0.0
      IF( (ZKM(I,JBAND) .LT. 12.0) .OR. (CLDFLG .EQ. 0.0) )  GO TO 17
CCC
CC    *** GOT HERE FOR CLOUDS, DAY OR NIGHT ****************************
      IKM = IKM+1
      CLDFG1 = 1.0
      IF( IKM.GT.1 )  GO TO 17
CCC
CC    *** GOT HERE FOR CLOUDS, ZKM(I,JBAND) = 12.0 KM ******************
CC        SET ALTITUDES OF ALL POINTS C (TO BE VIEWED FROM POINT V)
CC        EQUAL TO 12-KM.
      C12ALT = 12.0
      CALTCM = 1.0E+05*C12ALT
CC        THE NATURAL CLOUD MODEL (NCM) FUNCTION CFLOSF(ICC,CHI)
CC        COMPUTES THE PROBABILITY OF A CLOUD-FREE LINE-OF-SIGHT
CC        (CFLOS), GIVEN THE CLOUD COVERAGE IN TENTHS (ICC=1(1)11) AND
CC        ZENITH ANGLE CHI (DEGREES). HERE, WE WANT CFPS, A MEAN
CC        PROBABILITY OF A CFLOS FROM POINT P TO THE SUN, OBTAINED BY
CC        AN AVERAGE OVER THE NCM CLOUD-COVERAGE VALUES OF 0,3,5,8, AND
CC        10 TENTHS, OCCURRING WITH PROBABILITIES CCOVER(I,KMODEL)
CC        (I=1,5), FOR A SELECTED VALUE OF KMODEL. WE ASSUME THE SOLAR
CC        ZENITH ANGLE SOLZ AT THE SUBPOINT V' IS AN EXCELLENT APPROX-
CC        IMATION TO THOSE AT ALL POINTS P.
      IF( IDAYV .EQ. 0 )  GO TO 17
CCC
CC    *** GOT HERE FOR CLOUDS, DAY *************************************
      RTD = 180./PI
      SOLZ = RTD*ACOS( CSSOLZ )
      CFPS = CCOVER(1,KMODEL)*CFLOSF(1,SOLZ)
     1     + CCOVER(2,KMODEL)*CFLOSF(4,SOLZ)
     2     + CCOVER(3,KMODEL)*CFLOSF(6,SOLZ)
     3     + CCOVER(4,KMODEL)*CFLOSF(9,SOLZ)
     4     + CCOVER(5,KMODEL)*CFLOSF(11,SOLZ)
CC        THE ABOVE CALCULATIONS ARE DONE ONLY FOR THE FIRST
CC        ALTITUDE AT WHICH A CLOUD CALCULATION IS DONE.
CCC
   17 CONTINUE
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CC    *** GOT HERE FOR DAY OR NIGHT, REGARDLESS OF CLOUDS ************** UPWELL
CC                                                                       UPWELL
CC         PREPARE TO LOOP OVER NNADIR NADIR ANGLES CORRESPONDING TO     UPWELL
CC         FRACTILES OF OMEGAT, FRCTL.                                   UPWELL
      FNN = NNADIR                                                       UPWELL
      DO 70 J=1,NNADIR                                                   UPWELL
      JJP = J                                                            UPWELL
      FJ = J                                                             UPWELL
      FRCTL = (FJ-0.5)/FNN                                               UPWELL
CC         COMPUTE NADIR ANGLE BETA CORRESPONDING TO FRACTILE FRCTL.     UPWELL
      BETA = ACOS( 1.0-FRCTL*OMEGAT(I) )                                 UPWELL
CC         COMPUTE ZENITH ANGLE, CHI, OF POINT V VIEWED FROM POINT P     UPWELL
CC         (THE INTERSECTION POINT AT THE EARTH'S SURFACE OF THE RAY     UPWELL
CC         FROM POINT V AT NADIR ANGLE BETA).                            UPWELL
      CHI = ASIN( (1.0+DETALT/RE)*SIN(BETA) )                            UPWELL
CC         COMPUTE THE EARTH CENTRAL ANGLE, ALPHA, SUBTENDED BY POINTS P UPWELL
CC         AND V.                                                        UPWELL
      ALPHA = CHI-BETA                                                   UPWELL
      IF( CLDFGI .EQ. 0.0 )  GO TO 20                                    UPWELL
CCC                                                                      UPWELL
CC    *** GOT HERE FOR CLOUDS, DAY OR NIGHT **************************** UPWELL
CC         COMPUTE ZENITH ANGLE, CHIC, OF POINT V VIEWED FROM POINT C    UPWELL
CC         (THE INTERSECTION POINT AT THE 12-KM ALTITUDE SURFACE OF THE  UPWELL
CC         RAY FROM POINT V AT NADIR ANGLE BETA TO POINT P).             UPWELL
      CHIC = BETA                                                        UPWELL
      IF( DETALT .GT. C12ALT )  CHIC = ASIN( ((RE+DETALT)/(RE+C12ALT))*  UPWELL
     $                                             SIN(BETA) )           UPWELL
CC         COMPUTE THE EARTH CENTRAL ANGLE, ALPHAC, SUBTENDED BY POINTS C UPWELL
CC         AND V.  ALPHAC IS USED LATER.                                 UPWELL
      ALPHAC = CHIC - BETA                                               UPWELL
CC         EXPRESS CHI IN DEGREES (CHID) AS REQUIRED FOR INPUT TO        UPWELL
CC         SUBROUTINE CLDWT.                                             UPWELL
      CHID = CHI * RTD                                                   UPWELL
   20 CONTINUE                                                           UPWELL
CC                                                                       UPWELL
CC         PREPARE TO LOOP OVER NAZI AZIMUTH ANGLES.  RESET MAXIMUM      UPWELL
CC         NUMBER OF AZIMUTH ANGLES, NAZI, TO BE 1 IF IDAYV=0 OR MSM=1.  UPWELL
      IF( (IDAYV.EQ.0) .OR. (MSM.EQ.1) )  NAZI = 1                       UPWELL
CC         INITIALIZE AZIMUTH ANGLE.                                     UPWELL
      PIDNA = PI/FLOAT(NAZI)                                             UPWELL
      AZI = REFAZI-0.5*PIDNA                                             UPWELL
      DO 60 K=1,NAZI                                                     UPWELL
      KKP = K                                                            UPWELL
CC                                                                       UPWELL
CC         ALLOW SOLAR SPECULAR REFLECTION POINT TO BE COMPUTED ONLY ONCE UPWELL
CC         PER ALTITUDE.  HOWEVER, IF IDAYV=0 OR MSM.NE.2 WE DO NOT      UPWELL
CC         COMPUTE SPECULAR REFLECTION POINT AT ALL.                     UPWELL
      SPCLRX = SPCULR .AND. ((J+K).EQ.2)                                 UPWELL
      IF( (IDAYV.EQ.0) .OR. (MSM.NE.2) )  SPCLRX = .FALSE.               UPWELL
      AZI = AZI+PIDNA                                                    UPWELL
CC                                                                       UPWELL
CC         MUST SET LATITUDE AND LONGITUDE OF POINT P IN POSITN COMMON.  UPWELL
CC         USE REVISED HARC SUBROUTINE AGAGEO WITH POINT 1 BEING POINT V UPWELL
CC         AND POINT 2 BEING POINT P.                                    UPWELL
      CALL AGAGEO(DALTCM,PID2-DETLAT,DETLON,AZI,ALPHA,PALTCM,PSCLAT,     UPWELL
     $  POSLON)                                                          UPWELL
      POSLAT = PID2-PSCLAT                                               UPWELL
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CC        NOW HAVE LATITUDE AND LONGITUDE OF POINT P.                  UPWELL
CC        GET EARTH-CENTERED CARTESIAN COORDINATES OF POINT P.         UPWELL
      CALL GEOXYZ(POSALT,POSLAT,POSLON,RP(1),RP(2),RP(3))              UPWELL
CC        SET DIRECTION-COSINES UL, VL, AND WL OF POINT P FROM POINT V. UPWELL
      UL = RP(1)-XD                                                    UPWELL
      VL = RP(2)-YD                                                    UPWELL
      WL = RP(3)-ZD                                                    UPWELL
      RRI = 1.0/SQRT( UL*UL + VL*VL + WL*WL )                          UPWELL
      UL = UL*RRI                                                      UPWELL
      VL = VL*RRI                                                      UPWELL
      WL = WL*RRI                                                      UPWELL
      CALL VLIN(RP,1.0E+05,RP,0.0,0.0)                                 UPWELL
CC                                                                     UPWELL
      IF( CLDFGI .EQ. 0.0 )  GO TO 21                                  UPWELL
CCC                                                                    UPWELL
CC    *** GOT HERE FOR CLOUDS, DAY OR NIGHT *************************** UPWELL
CC        FOR POINT C, SET LATITUDE AND LONGITUDE IN POSITN COMMON AND UPWELL
CC        ALSO GET EARTH-CENTERED CARTESIAN COORDINATES.               UPWELL
CC        IF POINT V IS AT 12-KM ALTITUDE, POINT C IS AT POINT V.      UPWELL
      C12LAT = DETLAT   $   C12LON = DETLON                            UPWELL
      RC(1) = RV(1)   $   RC(2) = RV(2)   $   RC(3) = RV(3)            UPWELL
      IF( DETALT .EQ. C12ALT )  GO TO 21                               UPWELL
CC    *** GOT HERE FOR CLOUDS, DAY OR NIGHT, ZKM(I,JBAND) .GT. 12.0 **** UPWELL
      CALL AGAGEO(DALTCM,PID2-DETLAT,DETLON,AZI,ALPHAC,CALTCM,CCLAT,   UPWELL
     $                                                        C12LON)  UPWELL
      C12LAT = PID2 - CCLAT                                            UPWELL
      CALL GEOXYZ(C12ALT,C12LAT C12LON,RC(1),RC(2),RC(3))              UPWELL
      CALL VLIN(RC,1.0E+05,RC,0.0,0.0)                                 UPWELL
   21 CONTINUE                                                         UPWELL
CC                                                                     UPWELL
CC        SET FILPOS FOR CALL TO TRANS.                                UPWELL
CC        FILPOS PLAYS NO ROLE IF TRNSOPT .EQ. TRUE AND (AS SHOULD BE  UPWELL
CC        THE CASE) ONE USES THE SAME SPECTRAL LISTS AS ARE USED BY    UPWELL
CC        TRANSB IN PREPARING TAPOT=LTMTE.  HOWEVER,IF TRNSOPT .EQ.    UPWELL
CC        FALSE, FILPOS IS USED TO ACHIEVE NECESSARY REWINDS OF TAPOT  UPWELL
CC        AND AVOID UNNECESSARY REWINDS.                               UPWELL
      FILPOS = 1.0E+04                                                 UPWELL
CC                                                                     UPWELL
CC        START LOOP OVER WAVENUMBERS.                                 UPWELL
      NWAVEJ = NWAVE(JBAND)                                            UPWELL
      DO 58 L=1,NWAVEJ                                                 UPWELL
      LLP = L                                                          UPWELL
CC                                                                     UPWELL
CC        THE VARIABLES IJKL AND IKMJKL, NOT USED IN THE GRC VERSION,  UPWELL
CC        ARE USED IN THE SAI VERSION TO FACILITATE PRINT STATEMENTS.  UPWELL
      IJKL = I + J + K + L                                             UPWELL
      IKMJKL = IKM + J + K + L                                         UPWELL
CC                                                                     UPWELL
      ZLAM = 1.0E+04/WW(L)                                             UPWELL
      WDL = WW(L) - 0.5*DW(L)                                          UPWELL
      WDH = WW(L) + 0.5*DW(L)                                          UPWELL
      CALL SURRAD(2,MSM,DD,SPCLRX,IIP,JJP,KKP,LLP,ZLAM,0 ,RAD,UPS,UPPS, UPWELL
     $                                                     UCS,UPCS)   UPWELL
CC        NOW HAVE AT POINT P ON THE EARTH'S SURFACE THE EMITTED       UPWELL
CC        RADIANCE RAD(1) AND (IF IDAY=1 AND IDAYV=1) THE (UNATTENUATED) UPWELL
CC        REFLECTED RADIANCE OF SOLAR RADIATION RAD(2) AND THE PATH    UPWELL
CC        PARAMETERS UPS(IT,N,1) AND UPPS(IT,N,1) FOR THE INCOMING SOLAR UPWELL
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CC        RAY.  ALSO HAVE AEROSOL TRANSMITTANCE (TASP(L)) THROUGH AIRSOL
CC        COMMON FOR PATH FROM S TO P, WHICH WILL BE USED LATER.  ALSO
CC        HAVE AT POINT C THE PATH PARAMETERS UCS(IT,N) AND UPCS(IT,N)
CC        FOR THE INCOMING SOLAR RAY AND THE AEROSOL TRANSMITTANCE
CC        (TASC(L)) THROUGH AIRSOL COMMON FOR PATH S TO C, ALSO USED
CC        LATER.  THE PATH PARAMETERS ARE COMPUTED ONLY FOR L=1, BUT
CC        TASP(L) AND TASC(L) ARE COMPUTED FOR L=1,NWAVEJ.  WE WILL SOON
CC        GET SUM OF (1) ATTENUATED RADIANCE EMITTED FROM SURFACE AND
CC        (2) ATTENUATED ATMOSPHERIC EMISSION BETWEEN POINTS V AND P.
CC        TEMPORARILY USE UPRAD(K,L) FOR THIS SUM WHICH IS INDEPENDENT
CC        OF AZIMUTH.
CCCC
      IF( K .GT. 1 )  GO TO 30
CC        NEED CALL TRNSCO ONLY ON FIRST WAVENUMBER BECAUSE TRNSCO
CC        INTERNALLY LOOPS OVER THE WAVENUMBER LIST.
      IF( L .GT. 1 )  GO TO 27
CCC
CC    *** GOT HERE FOR DAY OR NIGHT, REGARDLESS OF CLOUDS **************
CC        FOR SOME APPLICATIONS IT IS DESIRABLE TO HAVE SUBROUTINE
CC        UPWELL RESULTS CORRESPONDING TO ZKM=0.0, EVEN THOUGH THE
CC        ROUTINE WAS NOT ORIGINALLY DESIGNED TO BE CALLED WITH ZKM=0.
CC        TO CIRCUMVENT THIS DIFFICULTY, WE DEVELOP A PSEUDO ZERO-
CC        ALTITUDE ALGORITHM WHICH EXPLOITS THE FEATURE OF SUBROUTINE
CC        STEP WHEREIN IT DOES NOT COMPUTE PATH ELEMENTS LESS THAN 10
CC        METERS IN LENGTH.  THUS, IF THE TOTAL PATH IS LESS THAN 10
CC        METERS, THEN SUBROUTINE STEP SETS NC TO ZERO.  WE DETECT SUCH
CC        A CONDITION BY SETTING A NEW VARIABLE NCNC EQUAL TO NC AFTER
CC        THE DOUBLE CALL TO SUBROUTINE STEPS IN SUBROUTINE TRNSCO AND
CC        CARRYING NCNC TO UPWELL VIA ONCNC COMMON (KNOWN ONLY TO TRNSCO
CC        AND UPWELL).  WE MUST ALSO RECOGNIZE THAT SUBROUTINE ATMRAD
CC        NORMALLY PERFORMS TWO OPERATIONS FOR (NC.GT.1) WHICH ARE NOT
CC        PERFORMED FOR (NC.LT.2).  THESE OPERATIONS ARE (1) REWINDING
CC        LTMTE AND (2) ZEROING THE SECOND HALVES OF THE U AND UP
CC        ARRAYS.  THUS, FOR (NC.EQ.0), WE WANT TO (AND DO) PERFORM
CC        THESE TWO OPERATIONS HERE IN UPWELL.  SUBROUTINE TRNSCO, FOR
CC        (NC.LT.2), WILL RETURN ZERO FOR THE AIR-PATH RADIANCE
CC        (BKGND BI(NBI)) AND UNITY FOR THE AIR-PATH TRANSMITTANCE
CC        (TRANS BI(NBI)).  THESE VALUES ARE PRECISELY THE VALUES
CC        APPROPRIATE FOR THE ALTITUDE EQUALLING ZERO, VALID OF COURSE
CC        FOR ALL NADIRS AND AZIMUTHS.  THUS, THE PSEUDO ZERO-ALTITUDE
CC        ALGORITHM NEED BE EXERCISED ONLY FOR THE FIRST NADIR AND THE
CC        FIRST AZIMUTH.  TO PROCEED WITH THE PSEUDO ZERO-ALTITUDE
CC        ALGORITHM, WE SELECT AN ALTITUDE ZKM LESS THAN 10 METERS, SAY
CC        ONE METER = 0.001 KM.  WE ALSO PRETEND THAT THE PATH LENGTH
CC        NEVER EXCEEDS 10 METERS, REGARDLESS OF THE NADIR ANGLE,
CC        PROVIDED IT DID NOT DO SO FOR THE FIRST NADIR.  THUS, WE
CC        DECREE THAT TRNSCO SHALL NOT BE CALLED FOR (J.GT.1) IF THE
CC        PATH LENGTH WAS LESS THAN 10 METERS FOR J=1.
CCC
      IF( J .GT. 1 )  GO TO 23
CC        FOLLOWING CALL TO TRNSCO OCCURS FOR I.GE.1, J=K=L=1.
CC        TRNSCO'S ARGUMENT-LIST DISTANCES MUST BE IN CM.
      CALL TRNSCO( RV, RP, RP, LBINT, RADSW )
      IF( NCNC .GT. 1 )  GO TO 25
CC        SINCE WE ARE SEEKING RESULTS FOR ZKM=0.0, PERFORM THE TWO
CC        ABOVE-DESCRIBED OPERATIONS NORMALLY PERFORMED BY SUBROUTINE
CC        ATMRAD.
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   22 REWIND LTMTE
      CALL XMIT ( -100, 0.,  U(1,1,2) )
      CALL XMIT ( -100, 0., UP(1,1,2) )
      GO TO 25
   23 IF( NCNC .GT. 1 )  GO TO 24
      GO TO 22
CC         FOLLOWING CALL TO TRNSCO OCCURS FOR I.GE.2, J.GE.2, K=L=1.
CC         TRNSCO'S ARGUMENT-LIST DISTANCES MUST BE IN CM.
   24 CALL TRNSCO( RV, RP, RP, LBINT, RADSW )
   25 CONTINUE
CC         WE ALSO NEED TO PRESERVE PATH PARAMETERS FOR PATH P TO V IN
CC         ARRAYS UPV AND UPPV.
      CALL XMIT ( 100, U (1,1,2), U PV)
      CALL XMIT ( 100, UP(1,1,2), UPPV)
      WRITE(6,1025)
 1025 FORMAT (1H0,45X,41H* * * PATH PARAMETERS, POINT P TO V * * */45X,*
     $(FROM SUBROUTINE UPWELL, FORMATS 1025,1027)*/2X,*TEMPERATURE/SPECI
     $ES.    ((U PV(M,N),N=1,NSPECS),M=1,2)*)
      WRITE(6,1026) ((M, (U PV(M,N),N=1,NSPECS)),M=1,2)
 1026 FORMAT (2X,I3,1P10E12.4)
      WRITE(6,1027)
 1027 FORMAT (1H0,1X,*TEMPERATURE/SPECIES.    ((UPPV(M,N),N=1,NSPECS),M=1
     $,2)*)
      WRITE(6,1025) ((M, (UPPV(M,N),N=1,NSPECS)),M=1,2)
CC
CC         FOR PATH P TO V, PRESERVE TAPV(L), TTPV(L), AND AEPV(L)
CC         (L=1,NWAVEJ) WHICH ARE DERIVED FROM DATASET-BI.  SEE
CC         SUBROUTINES TRNSCO AND ATMRAD FOR COMMENTS REGARDING TEMPORARY
CC         USE OF WORD-8 OF DATASET-BI FOR AEROSOL TRANSMITTANCE.
      LX = 0
      LINT = LBINT
   26 CALL PREV ( LINT,NBI )
      IF( NBI .EQ. 0 )  GO TO 27
      LX = LX + 1
      IF( LX .GT. 10 )  GO TO 27
      TTPV(LX) = Q(NBI+6)
      AEPV(LX) = Q(NBI+4)/DW(LX)
      Q(NBI+4) = 0.
      TAPV(LX) = Q(NBI+7)
      IQ(NBI+7) = 0
      GO TO 26
   27 CONTINUE
C
CC         THE NEXT STATEMENT PROVIDES THE ABOVE-MENTIONED SUM
CC         (TEMPORARILY CALLED UPRAD(K,L)) OF (1) EARTH'S SURFACE
CC         RADIANCE RAD(1) MULTIPLIED BY THE TOTAL TRANSMITTANCE TTPV(L)
CC         BETWEEN POINTS P AND V AND (2) THE ATMOSPHERIC EMISSION
CC         AEPV(L) BETWEEN POINTS V AND P.  THE DO-28 LOOP RECOGNIZES
CC         THIS SUM IS AZIMUTHALLY INDEPENDENT.
      UPRAD(K,L) = RAD(1)*TTPV(L) + AEPV(L)
      IF( NAZI .EQ. 1 )  GO TO 29
      DO 28 KKK=2,NAZI
      UPRAD(KKK,L) = UPRAD(1,L)
   28 CONTINUE
   29 CONTINUE
      IF( IJKL .EQ. 4 )  WRITE(6,100)
  100 FORMAT (1H1,44X,43H* * *  OUTPUT FROM SUBROUTINE UPWELL  * * *)
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      IF( IJKL .EQ. 4 )  WRITE(6,101)                                   UPWELL
  101 FORMAT (1HO,1X,107H  I  J  K  L        WDL           WDH         Z UPWELL
     $LAM           RAD(1)          TTPV          AEPV          TAPV )  UPWELL
      WRITE(6,102) I,J,K,L,WDL,WDH,ZLAM,RAD(1),TTPV(L),AEPV(L),TAPV(L)  UPWELL
  102 FORMAT (2X,4I3,1P7(E14.5))                                        UPWELL
   30 CONTINUE                                                          UPWELL
CCCC                                                                    UPWELL
CC        UPRAD IS OUR ANSWER IF IDAYV=0 AND IF NO CLOUDS ARE INCLUDED.  UPWELL
      IF( CLDFG1 .EQ. 0.0 )  GO TO 36                                   UPWELL
CCC                                                                     UPWELL
CC    *** GOT HERE FOR CLOUDS, DAY OR NIGHT **************************** UPWELL
CC        PREPARE TO CALL NCM SUBROUTINE CLDWT TO GET THE NCDSET-MEMBER  UPWELL
CC        ARRAYS FOR WEIGHTS CORRESPONDING TO THE                       UPWELL
CC        VARIOUS CLOUD CONFIGURATIONS OR SETS (WT), AND, AT 12-KM      UPWELL
CC        ALTITUDE (POINT C) ALONG THE PATH FROM POINT P TO POINT V, THE UPWELL
CC        TOP-CLOUD EMISSION RADIANCES (EMISS) AND (IF IDAYV=1) THE     UPWELL
CC        TRANSFER COEFFICIENTS (TRANS) FOR THE TOP-CLOUD REFLECTION    UPWELL
CC        OF THE SOLAR RADIATION.                                       UPWELL
CC        WT(I), FOR ANY OF THE 10 LOCATION-SEASON AVERAGED STATISTICAL UPWELL
CC        CLOUD MODELS (KMODEL=1,10), IS THE PROBABILITY THAT (A) THE   UPWELL
CC        CLOUD-CONFIGURATION SET INDICATED BY THE INDEX I OCCURS AND   UPWELL
CC        (B) THE DETECTOR LOS AT ZENITH ANGLE CHI INTERSECTS THE CLOUD- UPWELL
CC        CONFIGURATION SET.  THE PROBABILITY OF THE DETECTOR'S LOS     UPWELL
CC        INTERSECTING CLOUDS IS SUM(WT(I)) (I=1,IDX-1).                UPWELL
CC                                                                      UPWELL
CC        BEFORE PROCEEDING TO CALL SUBROUTINE CLDWT, WE COMPUTE THE AIR UPWELL
CC        EMISSION BETWEEN POINTS C AND V (ARCVA(IKM,J,L))              UPWELL
CC        AND THE AIR TRANSMITTANCE (BOTH MOLECULAR AND AEROSOL) FROM   UPWELL
CC        POINT C TO POINT V.  THE TOTAL TRANSMITTANCE IS TTCV AND THE  UPWELL
CC        AEROSOL TRANSMITTANCE IS TACV.  ALL OF THESE QUANTITIES ARE   UPWELL
CC        INDEPENDENT OF AZIMUTH, SO THEY NEED BE COMPUTED ONLY FOR K=1. UPWELL
      IF( ZKM(I,JBAND) .GT. 12.0 )  GO TO 31                            UPWELL
      IF( ( J .GT. 1 ) .OR. ( K .GT. 1 ) )  GO TO 33                    UPWELL
      AECV(L) = 0.0                                                     UPWELL
      TTCV(L) = 1.0                                                     UPWELL
      TACV(L) = 1.0                                                     UPWELL
      IF( L .GT. 1 )  GO TO 33                                          UPWELL
CC        ZERO ARRAYS PRESERVING PATH PARAMETERS FOR PATH V TO C.  NEED  UPWELL
CC        BE DONE ONLY ONCE FOR ZKM(I,JBAND) = 12.0 .                   UPWELL
      CALL XMIT (-100, 0., U CV )                                       UPWELL
      CALL XMIT (-100, 0., UPCV )                                       UPWELL
      GO TO 33                                                          UPWELL
   31 CONTINUE                                                          UPWELL
      IF( ( K .GT. 1 ) .OR. ( L .GT. 1 ) )  GO TO 33                    UPWELL
CC        FOLLOWING CALL TO TRNSCO OCCURS FOR CLDFLG.EQ.1,              UPWELL
CC        ZKM(I,JBAND).GT.12.0, J.GE.1, K=L=1 .                         UPWELL
      CALL TRNSCO( RV, RC, RC, LBINT, RADSW )                           UPWELL
CC        WE ALSO NEED TO PRESERVE PATH PARAMETERS FOR PATH C TO V IN   UPWELL
CC        ARRAYS UCV AND UPCV.                                          UPWELL
      CALL XMIT ( 100, U (1,1,2), U CV)                                 UPWELL
      CALL XMIT ( 100, UP(1,1,2), UPCV)                                 UPWELL
      WRITE(6,1031)                                                     UPWELL
 1031 FORMAT (1HO,45X,41H* * * PATH PARAMETERS, POINT C TO V * * */47X,* UPWELL
     $(FROM SUBROUTINE UPWELL, FORMATS 1031,1033)*/2X,*TEMPERATURE/SPECI UPWELL
     $ES.   ((U CV(M,N),N=1,NSPECS),M=1,2)*)                            UPWELL
      WRITE(6,1026) ((M, (U CV(M,N),N=1,NSPECS)),M=1,2)                 UPWELL
      WRITE(6,1033)                                                     UPWELL
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 1033 FORMAT (1HC,1X,*TEMPERATURE/SPECIES.   ((UPCV(M,N),N=1,NSPECS),M=1
     $,2)*)
      WRITE(6,1036) ((M, (UPCV(M,N),N=1,NSPECS)),M=1,2)
CC
CC          FOR PATH C TO V, PRESERVE TACV(L), TTCV(L), AND AECV(L)
CC          (L=1,NWAVEJ) WHICH ARE DERIVED FROM DATASET-BI.  SEE
CC          SUBROUTINES TRNSCO AND ATMRAD FOR COMMENTS REGARDING TEMPORARY
CC          USE OF WORD-8 OF DATASET-BI FOR AEROSOL TRANSMITTANCE.
      LX = 0
      LINT = LBINT
   32 CALL PREV ( LINT,NBI )
      IF( NBI .EQ. 0 )  GO TO 33
      LX = LX + 1
      IF( LX .GT. 10 )  GO TO 33
      TTCV(LX) = Q(NBI+6)
      AECV(LX) = Q(NBI+4)/DW(LX)
      Q(NBI+4) = 0.
      TACV(LX) = Q(NBI+7)
      IQ(NBI+7) = 0
      GO TO 32
   33 CONTINUE
CC
      IF( IKMJKL .EQ. 4 )  WRITE(6,103)
  103 FORMAT (1H0,1X,*  I   J  K  L                                ZLAM
     $            TTCV              AECV              TACV*)
      WRITE(6,104) I,J,K,L,ZLAM,TTCV(L),AECV(L),TACV(L)
  104 FORMAT (2X,4I3,28X,1PE14.5,14X,3(E14.5))
CC
      IF( K .GT. 1 )  GO TO 34
CC          AECV(L) IS INDEPENDENT OF AZIMUTH, SO WE PRESERVE IT WITH A
CC          NOTATION TO DENOTE IT IS THE AZIMUTHAL AVERAGE FOR THE
CC          CURRENT VALUES OF IKM, J, AND L.
      ARCVA(IKM,J,L) = AECV(L)
   34 CONTINUE
CC
CC          IN ORDER THAT SUBROUTINE TRANSF IN THE NCM, CALLED BY
CC          SUBROUTINE CLDWT, WILL KNOW WHETHER OR NOT THE SUN IS ABOVE OR
CC          BELOW THE HORIZON, SET ITFLAG IN THE FLAGS COMMON (USED IN THE
CC          NCM AND INCLUDED HERE IN SUBROUTINE UPWELL).
      ITFLAG = 0
      IF( IDAYV .EQ. 1 )  ITFLAG = 1
      CALL CLDWT(ZLAM,CHID)
CC          SUBROUTINE CLDWT HAS PROVIDED, THROUGH COMMON CLDWT, THE
CC          ARRAYS WT, TRANS, AND EMISS, OF LENGTHS IDX, IDX-1, AND IDX-1,
CC          RESPECTIVELY.  IDX EQUALS 160 FOR A FULL SET OF 159 CONFIG-
CC          URATIONS AND IS LESS FOR A RESTRICTED SET.
CC
CC          TO FACILITATE COMPUTING THE RADIANCE DISTRIBUTION FUNCTION
CC          RESULTING FROM THE STATISTICAL TREATMENT OF NATURAL CLOUDS,
CC          START FORMING A NEW RADIANCE DISTRIBUTION FUNCTION(UPRADC)
CC          AND CORRESPONDING WEIGHTS(WTC).  IF NCDSET IS THE NUMBER OF
CC          STATISTICAL CLOUD SETS, WITH A  MAXIMUM OF 159, FOR KMODEL=
CC          1,10, THEN THE LENGTH (II) OF THE ARRAYS UPRADC AND WTC WILL
CC          BE II=NCDSET+1 IF IDAYV=0 OR II=NCDSET+2 IF IDAYV=1.
CC          (THIS STATEMENT DOES NOT INCLUDE THE ZERO-VALUE MEMBERS ADDED
CC          (AFTER STATEMENT LABEL 55) FOR INTERPOLATION PURPOSES.)
CC
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CC        TO FACILITATE ASSESSING THE RELATIVE IMPORTANCE OF EMISSION     UPWELL
CC        AND REFLECTION CONTRIBUTIONS, PRESERVE THE EMISSION COMPONENT  UPWELL
CC        OF UPRADC IN ANOTHER ARRAY (UPRDC1).                            UPWELL
      NCDSET = IDX-1                                                      UPWELL
      SUMWTC = 0.0                                                        UPWELL
      DO 35 M=1,NCDSET                                                    UPWELL
CC        MULTIPLY THE SPECTRAL RADIANCE FROM THE NCM, EXPRESSED IN       UPWELL
CC        UNITS OF WATTS / (KM**2 SR MICRON), BY 1.0E-14*(ZLAM**2) TO     UPWELL
CC        OBTAIN WATTS / (CM**2 SR CM-1).                                 UPWELL
CC        ALSO INCLUDE TRANSMITTANCE BETWEEN POINTS C AND V.              UPWELL
      UPRADC(M) = (1.0E-14 * ZLAM**2) * EMISS(M) * TTCV(L)                UPWELL
      UPRDC1(M) = UPRADC(M)                                               UPWELL
      WTC(M) = WT(M)                                                      UPWELL
      SUMWTC = SUMWTC + WTC(M)                                            UPWELL
   35 CONTINUE                                                            UPWELL
      II = NCDSET+1                                                       UPWELL
CC        AT THIS POINT, II WILL NORMALLY BE 160.                         UPWELL
CC                                                                        UPWELL
CC        NOW USE FACT THAT RADIANCE AT POINT V DUE TO AIR EMISSION       UPWELL
CC        BETWEEN POINTS V AND P CAN BE BROKEN INTO TWO PORTIONS...       UPWELL
CC                  AEPV(L) = AECV(L) + AEPC(L)*TTCV(L)                   UPWELL
CC        THUS      AEPC(L)*TTCV(L) = AEPV(L) - AECV(L)                   UPWELL
CC        HENCE WE NEED TO SUBTRACT AECV(L) FROM UPRAD(K,L) IN ORDER FOR UPWELL
CC        UPRADC(II) TO CONTAIN THE (ATTENUATED) AIR EMISSION BETWEEN     UPWELL
CC        POINTS P AND C.                                                 UPWELL
      UPRADC(II) = UPRAD(K,L) - AECV(L)                                   UPWELL
      UPRDC1(II) = UPRADC(II)                                             UPWELL
CC                                                                        UPWELL
CC        WE NEED THE MEAN PROBABILITY OF A CLOUD-FREE LOS FROM           UPWELL
CC        POINT P TO POINT V (AT ZENITH ANGLE CHI CORRESPONDING TO NADIR UPWELL
CC        ANGLE BETA.  AS NOTED BEFORE, THE PROBABILITY OF THE            UPWELL
CC        DETECTOR'S LOS INTERSECTING CLOUDS IS SUM(WT(I)) (I=1,IDX-1).  UPWELL
CC        HENCE, WE TAKE (1.-SUM(WT(I))) AS THE DESIRED PROBABILITY OF A UPWELL
CC        CLOUD-FREE LOS, CFPV.                                           UPWELL
      CFPV = 1. - SUMWTC                                                  UPWELL
      WTC(II) = CFPV                                                      UPWELL
CC        THIS WTC IS THE ONE OBTAINING FOR NIGHT.  FOR DAY, WTC IS       UPWELL
CC        RESET AFTER LOOP DO-52.                                         UPWELL
CCC                                                                       UPWELL
CC        IF IDAYV=1, MUST ADD IN CLOUD-REFLECTED SOLAR RADIATION,        UPWELL
CC        AFTER ADDING IN SURFACE-REFLECTED SOLAR RADIATION.              UPWELL
CC    *** GOT HERE FOR CLOUDS, DAY OR NIGHT ***************************** UPWELL
      IF( IDAYV.EQ.O )  GO TO 55                                          UPWELL
CCC                                                                       UPWELL
CC    *** GOT HERE FOR CLOUDS,DAY *************************************** UPWELL
      GO TO 37                                                            UPWELL
CCC                                                                       UPWELL
   36 CONTINUE                                                            UPWELL
CC    *** GOT HERE FOR NO CLOUDS, DAY OR NIGHT ************************** UPWELL
CC        IF IDAYV=1, MUST ADD IN SURFACE-REFLECTED SOLAR RADIATION.      UPWELL
      IF( IDAYV.EQ.O ) GO TO 58                                           UPWELL
CCC                                                                       UPWELL
   37 CONTINUE                                                            UPWELL
CC    *** GOT HERE FOR DAY, WITH OR WITHOUT CLOUDS ********************** UPWELL
CC        EARLIER, SUBROUTINE TRNSCO CALLED SUBROUTINE PATH FOR THE PATH UPWELL
CC        FROM V TO P AND WE SAVED THE PATH PARAMETERS U(IT,N,2) AND UP( UPWELL
CC        IT,N,2) AS UPV(IT,N) AND UPPV(IT,N).  NOW ADD PATH PARAMETERS  UPWELL
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CC        FOR SEGMENTS SP AND PV.  NEED BE DONE ONLY FOR K=L=1, BUT THEY UPWELL
CC          MUST BE SAVED IN USPV AND UPSPV ARRAYS.                       UPWELL
      IF( K .GT. 1 )  GO TO 42                                            UPWELL
      IF( L .GT. 1 )  GO TO 41                                            UPWELL
      DO 40 NN=1,NSPECS                                                   UPWELL
      DO 40 LL=1,2                                                        UPWELL
CCC                                                                       UPWELL
CC        ONLY TWO TEMPERATURES (SINCE SHELLS LIMITS THE ATMOSPHERIC      UPWELL
CC        TEMPERATURE TO 300 DEG K) ARE NEEDED FOR THE AMBIENT            UPWELL
CC        ATMOSPHERE, BUT NTEMP MUST BE SET TO 10 AND NOT TO 2 TO BE      UPWELL
CC        CONSISTENT WITH THE DIMENSIONING OF THE U AND UP ARRAYS IN      UPWELL
CC        SUBROUTINE TRANS.  THE FIRST HALVES OF THE U AND UP ARRAYS      UPWELL
CC        WERE ZEROED IN TRNSCO.  TRANS (STATEMENT LABELED 30) WILL       UPWELL
CC        DETECT THE ZERO VALUES OF U AND UP FOR TEMPERATURE-INDEXES 3    UPWELL
CC        THROUGH 10 AND WASTE LITTLE TIME IN COMPUTING THE               UPWELL
CC        TRANSMITTANCE FOR ZERO VALUES OF THE PATH PARAMETERS.           UPWELL
CCC                                                                       UPWELL
      U SPV(LL,NN) = U PV(LL,NN) + U PS(LL,NN,1)                          UPWELL
      UPSPV(LL,NN) = UPPV(LL,NN) + UPPS(LL,NN,1)                          UPWELL
   40 CONTINUE                                                            UPWELL
      WRITE(6,1040)                                                       UPWELL
 1040 FORMAT (1H0,42X,48H* * PATH PARAMETERS, SUN TO POINT P TO V * *    UPWELL
     $*/45X,*(FROM SUBROUTINE UPWELL, FORMATS 1040,1042)*/2X,*TEMPERATUR UPWELL
     $E/SPECIES.    ((U SPV(M,N),N=1,NSPECS),M=1,2)*)                     UPWELL
      WRITE(6,1026) ((M, (U SPV(M,N),N=1,NSPECS)),M=1,2)                  UPWELL
      WRITE(6,1042)                                                       UPWELL
 1042 FORMAT (1H0,1X,*TEMPERATURE/SPECIES.    ((UPSPV(M,N),N= ,NSPECS),M= UPWELL
     $1,2)*)                                                              UPWELL
      WRITE(6,1026) ((M, (UPSPV(M,N),N=1,NSPECS)),M=1,2)                  UPWELL
   41 CONTINUE                                                            UPWELL
CCCC                                                                      UPWELL
CC        ENTRY TRANS1 IN SUBROUTINE TRANS IS PROVIDED 12/29/78 TO        UPWELL
CC        AVOID CONFLICT IN SUBROUTINE UPWELL BETWEEN THE ARRAY TRANS     UPWELL
CC        IN COMMON CLDWT AND THE CALL TO SUBROUTINE TRANS.               UPWELL
CC        NOTE...WE ARE CALLING SUBROUTINE TRANS WITH THE ARRAYS          UPWELL
CC        USPV(10,10) AND UPSPV(10,10) WHICH IS SATISFACTORY FOR          UPWELL
CC        SUBROUTINE TRANS' CURRENT USE OF M = 1 .  IN GENERAL,           UPWELL
CC        SUBROUTINE TRANS EXPECTS ARRAYS U(IT,N,2) AND UP(IT,N,2) WHEN   UPWELL
CC        BEING CALLED WITH M=1.                                          UPWELL
      CALL TRANS1( NTEMP, 1, USPV, UPSPV, FK, WDL, WDH, TAU, ABC,         UPWELL
     $                               TMSPV(L), TRNSOPT, FILPOS )          UPWELL
CCCC                                                                      UPWELL
CC        TRANS HAS RETURNED THE TOTAL MOLECULAR TRANSMITTANCE TMSPV(L)   UPWELL
CC        FOR THE TOTAL PATH (SP+PV), WITH ACCOUNT OF NSPECS SPECIES.     UPWELL
CC                                                                        UPWELL
CC        GET TOTAL TRANSMITTANCE BY INCLUDING AEROSOLS.                  UPWELL
CC        USE AEROSOL TRANSMITTANCE TASP(L) FROM SUBROUTINE SURRAD FOR    UPWELL
CC        PATH SP WITH AEROSOL TRANSMITTANCE TAPV(L) FROM SUBROUTINE      UPWELL
CC        TRNSCO'S CALL TO SUBROUTINE ATMRAD FOR PATH PV TO GET THE       UPWELL
CC        AEROSOL TRANSMITTANCE FOR THE TOTAL PATH SPV=(SP+PV).           UPWELL
      TTSPV(L) = TMSPV(L) * (TASP(L) * TAPV(L))                           UPWELL
CC        NOW HAVE TOTAL MOLECULAR AND AEROSOL TRANSMITTANCE FOR          UPWELL
CC        SURFACE-REFLECTED SOLAR RAY.                                    UPWELL
   42 CONTINUE                                                            UPWELL
CC                                                                        UPWELL
CC        IN FOLLOWING EXPRESSION, ONLY RAD(2) MAY DEPEND ON AZIMUTH,     UPWELL
CC        WHICH IT WILL FOR NON-LAMBERTIAN SURFACE MATERIALS (MSM.GT.1). UPWELL
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```
      UPRAD(K,L) = UPRAD(K,L) + TTSPV(L)*RAD(2)                         UPWELL
CC         NOW HAVE TOTAL UPWELLING RADIANCE DIRECTED FROM POINT P      UPWELL
CC         TO POINT V (WITHOUT ANY CLOUDS), THE FIRST TERM BEING THE SUM UPWELL
CC         OF THE ATTENUATED GROUND-SURFACE EMISSION AND AIR EMISSION   UPWELL
CC         BETWEEN POINTS P AND V AND THE SECOND TERM BEING THE         UPWELL
CC         ATTENUATED SURFACE-REFLECTED SOLAR RAY.                      UPWELL
      IF( IJKL .EQ. 4 )  WRITE(6,105)                                   UPWELL
  105 FORMAT (1H0,1X,*  I  J  K  L                                 ZLAM UPWELL
     $          RAD(2)          TTSPV          TMSPV          TASP*)    UPWELL
      WRITE(6,106) I,J,K,L,ZLAM,RAD(2),TTSPV(L),TMSPV(L),TASP(L)        UPWELL
  106 FORMAT (2X,4I3,28X,1P5(E14.5))                                    UPWELL
      IF( CLDFG1.EQ.0.0 )  GO TO 58                                     UPWELL
CCC                                                                     UPWELL
CC    *** GOT HERE FOR DAY, WITH CLOUDS ******************************** UPWELL
CC         WE MUST CONVERT THE TRANSFER COEFFICIENTS TRANS INTO         UPWELL
CC         RADIANCES FOR THE CLOUD-REFLECTED SOLAR RADIATION.  TO DO SO, UPWELL
CC         WE NEED THE SOLAR SPECTRAL IRRADIANCE  E (WATTS/(CM**2 CM-1)) UPWELL
CC         (NORMAL TO THE PATH TO THE SUN) AT THE 12-KM ALTITUDE POINT  UPWELL
CC         ON THE V-TO-P PATH.  HERE WE SHALL USE THE VALUE, SOLIRR(L)=E, UPWELL
CC         PREVIOUSLY OBTAINED BY A CALL TO SUBROUTINE SOLRAD FROM      UPWELL
CC         SUBROUTINE SURRAD AND AVAILABLE THROUGH SOLARP COMMON.       UPWELL
CC                                                                      UPWELL
CC         WE ALSO INCLUDE AIR TRANSMITTANCE (TTSCV(L)) ABOVE 12-KM     UPWELL
CC         ALTITUDE, ALONG THE PATH FROM S TO C TO V.  TTSCV(L) IS GIVEN UPWELL
CC         BY THE PRODUCT OF THE MOLECULAR TRANSMITTANCE (TMSCV(L)) AND UPWELL
CC         THE AEROSOL TRANSMITTANCE (TASC(L)*TACV(L)).                 UPWELL
CC         TMSCV(L) WILL BE COMPUTED BY SUBROUTINE TRANS, GIVEN THE PATH UPWELL
CC         PARAMETERS USCV AND UPSCV.  FROM TRNSCO'S CALL TO PATH WE HAVE UPWELL
CC         THE PATH PARAMETERS U(IT,N,2) AND UP(IT,N,2) (WHICH WE SAVED UPWELL
CC         AS UCV(IT,N) AND UPCV(IT,N) FOR THE PATH FROM POINT V TO POINT UPWELL
CC         C.  THE PATH PARAMETERS UCS(IT,N) AND UPCS(IT,N) WERE OBTAINED UPWELL
CC         WITH THE CALL TO SUBROUTINE SURRAD.                          UPWELL
CC         ADD THE PATH PARAMETERS FOR SEGMENTS SC AND CV.  NEED BE DONE UPWELL
CC         ONLY FOR K=L=1, BUT THEY MUST BE SAVED IN USCV AND UPSCV     UPWELL
CC         ARRAYS.                                                      UPWELL
      IF( K .GT. 1 )  GO TO 50                                          UPWELL
      IF( L .GT. 1 )  GO TO 45                                          UPWELL
      DO 44 NN=1,NSPECS                                                 UPWELL
      DO 44 LL=1,2                                                      UPWELL
      U SCV(LL,NN) = U CV(LL,NN) + U CS(LL,NN)                          UPWELL
      UPSCV(LL,NN) = UPCV(LL,NN) + UPCS(LL,NN)                          UPWELL
   44 CONTINUE                                                          UPWELL
      WRITE(6,1044)                                                     UPWELL
 1044 FORMAT (1H0,42X,48H* * PATH PARAMETERS, SUN TO POINT C TO V * *   UPWELL
     $*/44X,*(FROM SUBROUTINE UPWELL, FORMATS 1044,1046)*/2X,*TEMPERATUR UPWELL
     $E/SPECIES.   ((U SCV(M,N),N=1,NSPECS),M=1,2)*)                    UPWELL
      WRITE(6,1026) ((M, (U SCV(M,N),N=1,NSPECS)),M=1,2)                UPWELL
      WRITE(6,1046)                                                     UPWELL
 1046 FORMAT (1H0,1X,*TEMPERATURE/SPECIES.   ((UPSCV(M,N),N=1,NSPECS),M= UPWELL
     $1,2)*)                                                            UPWELL
      WRITE(6,1026) ((M, (UPSCV(M,N),N=1,NSPECS)),M=1,2)                UPWELL
   45 CONTINUE                                                          UPWELL
CC         NOTE...WE ARE CALLING SUBROUTINE TRANS WITH THE ARRAYS       UPWELL
CC         USCV(10,10) AND UPSCV(10,10) WHICH IS SATISFACTORY FOR       UPWELL
CC         SUBROUTINE TRANS' CURRENT USE OF M = 1 .  IN GENERAL,        UPWELL
CC         SUBROUTINE TRANS EXPECTS ARRAYS U(IT,N,2) AND UP(IT,N,2) WHEN UPWELL
CC         BEING CALLED WITH M=1.                                       UPWELL
```

```
      CALL TRANS1( NTEMP, 1, USCV, UPSCV, FK, WDL, WDH, TAU, ABC,         UPWELL
     $                                TMSCV(L), TRNSOPT, FILPOS )         UPWELL
CC         TRANS HAS RETURNED THE TOTAL MOLECULAR TRANSMITTANCE TMSCV(L)  UPWELL
CC         FOR THE TOTAL PATH (SC+CV).  USE AEROSOL TRANSMITTANCE TASC(L) UPWELL
CC         FROM SUBROUTINE SURRAD FOR PATH SC WITH AEROSOL TRANSMITTANCE  UPWELL
CC         TACV(L) FROM TRNSCO'S CALL TO SUBROUTINE ATMRAD FOR PATH CV TO UPWELL
CC         GET THE AEROSOL TRANSMITTANCE FOR THE TOTAL PATH SCV=(SC+CV).  UPWELL
      TTSCV(L) = TMSCV(L) * (TASC(L)*TACV(L))                             UPWELL
CC         NOW HAVE TOTAL MOLECULAR AND AEROSOL TRANSMITTANCE FOR CLOUD-  UPWELL
CC         REFLECTED SOLAR RAY.                                           UPWELL
      IF( IKMJKL .EQ. 4 )  WRITE(6,107)                                   UPWELL
  107 FORMAT (1H0,1X,*  I   J  K  L                                  ZLAM UPWELL
     $                   TTSCV            TMSCV          TASC*)           UPWELL
      WRITE(6,104) I,J,K,L,ZLAM,TTSCV(L),TMSCV(L),TASC(L)                 UPWELL
CCC                                                                       UPWELL
   50 CONTINUE                                                            UPWELL
CC         NOW GET A CONTRIBUTION TO THE TOTAL UPWELLING RADIANCE         UPWELL
CC         DIRECTED FROM POINT C TO POINT V, THE FIRST TERM BEING THE     UPWELL
CC         CLOUD-SURFACE EMISSION ATTENUATED BETWEEN POINTS C AND V AND   UPWELL
CC         THE SECOND TERM BEING THE ATTENUATED CLOUD-REFLECTED SOLAR     UPWELL
CC         RAY.                                                           UPWELL
      DO 52 M=1,NCDSET                                                    UPWELL
      UPRADC(M) = UPRADC(M) + SOLIRR(L) * TRANS(M) * TTSCV(L)             UPWELL
   52 CONTINUE                                                            UPWELL
CC                                                                        UPWELL
CC         AT THIS POINT, II WILL NORMALLY BE 160 .                       UPWELL
CC         SINCE WE ARE ABOUT TO INCLUDE THE TWO-LEG CFLOS, WE MUST       UPWELL
CC         MULTIPLY THE PROBABILITY OF THE (NIGHTTIME) ONE-LEG CFLOS BY   UPWELL
CC         THE PROBABILITY OF NOT HAVING THE SECOND (DAYTIME) LEG.        UPWELL
      WTC(II) = CFPV * ( 1. - CFPS )                                      UPWELL
CC         INCLUDE TWO-LEG CFLOS                                          UPWELL
      II = II + 1                                                         UPWELL
CC         AT THIS POINT, II WILL NORMALLY BE 161 .                       UPWELL
      UPRDC1(II) = UPRADC(II-1)                                           UPWELL
      UPRADC(II) = UPRADC(II-1) + RAD(2) * TTSPV(L)                       UPWELL
      WTC(II) = CFPS * CFPV                                               UPWELL
CC    *** GOT HERE FOR CLOUDS, DAY ************************************** UPWELL
   55 CONTINUE                                                            UPWELL
CC                                                                        UPWELL
CC    *** GOT HERE FOR CLOUDS, DAY OR NIGHT ***************************** UPWELL
CC         SORT THE RADIANCE ARRAY UPRADC IN INCREASING ORDER AND CARRY   UPWELL
CC         ALONG THE ARRAYS UPRDC1 AND WTC.  BEFORE SORTING, AUGMENT THE  UPWELL
CC         THREE ARRAYS WITH THE MEMBERS UPRADC(II+1) = 0.0, UPRDC1(II+1) UPWELL
CC         = 0.0, AND WTC(II+1) = 0.0, RESPECTIVELY.  DOING THIS ALLOWS   UPWELL
CC         SUBROUTINE LINEAR TO INTERPOLATE WITHIN ITS GIVEN ARRAY IF THE UPWELL
CC         WEIGHT OF THE NORMALLY SMALLEST MEMBER EXCEEDS THE SMALLEST    UPWELL
CC         FRACTILE (NOW 0.10) FOR WHICH AN INTEGRAL-DISTRIBUTION VALUE   UPWELL
CC         IS REQUESTED.                                                  UPWELL
      II = II + 1                                                         UPWELL
CC         AT THIS POINT, II WILL NORMALLY BE 161 FOR NIGHT AND 162 FOR   UPWELL
CC         DAY.                                                           UPWELL
      UPRADC(II) = 0.0                                                    UPWELL
      WTC(II) = 0.0                                                       UPWELL
      UPRDC1(II) = 0.0                                                    UPWELL
      IF( ( IKM .GE. 1 ) .AND. ( IKM .LE. 3 ) )  WRITE(6,1055)            UPWELL
     $                        (UPRADC(N),UPRDC1(N),WTC(N),N=1,II)         UPWELL
 1055 FORMAT (*0  BEFORE SORTING,  WE HAVE (FOR M=1,162) THE TRIPLETS UP UPWELL
```

```
     $RADC(M),UPRDC1(M),WTC(M)=*/(5X,1P9E12.4))
      CALL SORTLJ( UPRADC, UPRDC1, WTC, II, -1 )
CC         SUM THE WEIGHTS AND NORMALIZE THE SUM TO UNITY.
      DO 56 M=2,II
      WTC(M) = WTC(M) + WTC(M-1)
   56 CONTINUE
      WTCIIV = 1.0/WTC(II)
      DO 57 M=1,II
      WTC(M) = WTCIIV*WTC(M)
   57 CONTINUE
      IF( ( IKM .GE. 1 ) .AND. ( IKM .LE. 3 ) )  WRITE(6,1056)
     $                              (UPRADC(N),UPRDC1(N),WTC(N),N=1,II)
 1056 FORMAT (*0   AFTER SORTING AND SUMMING WEIGHTS, WE HAVE (FOR M=1,1
     $62) THE TRIPLETS UPRADC(M),UPRDC1(M),SUMWTC(M)=*/(5X,1P9E12.4))
CC         INTERPOLATE TO OBTAIN THE INDICATED PERCENTILES.
CC         RESULT IS STORED IN RXXX(K,L).
      CALL LINEAR ( 0.10,R010(K,L),WTC,UPRADC,II )
      CALL LINEAR ( 0.25,R025(K,L),WTC,UPRADC,II )
      CALL LINEAR ( 0.50,R050(K,L),WTC,UPRADC,II )
      CALL LINEAR ( 0.90,R090(K,L),WTC,UPRADC,II )
      R100(K,L) = UPRADC(II)
CC         STATEMENT 58 IS FOR WAVENUMBER LOOP ON INDEX L
   58 CONTINUE
CC         STATEMENT 60 IS FOR AZIMUTH LOOP ON INDEX K
   60 CONTINUE
CCC
CCC        WRITE OUT UPRAD(K,L)  FOR CURRENT VALUE OF II AND JJ.
CCC        WRITE OUT  RXXX(K,L)  FOR CURRENT VALUE OF II AND JJ, ONLY
CCC        IF CLDFG1 = 1.0 .
      WRITE(8)  ((UPRAD(K,L),K=1,NAZI),L=1,NWAVEJ)
      IF( CLDFG1 .EQ. 1.0 )  WRITE(8)  (((R010(K,L),R025(K,L),R050(K,L),
     $ R090(K,L),R100(K,L)), K=1,NAZI), L=1,NWAVEJ)
CCC
CC         COMPUTE AVERAGES OVER AZIMUTH ANGLES K AT WAVENUMBERS
CC         L=1,NWAVEJ,  NADIR ANGLE J, AND ALTITUDE I.
      FINAZ = 1.0/FLOAT(NAZI)
      DO 64 L=1,NWAVEJ
      SUMM = 0.0
      DO 62 K=1,NAZI
      SUMM = SUMM + UPRAD(K,L)
   62 CONTINUE
      UPRADA(I,J,L) = FINAZ*SUMM
   64 CONTINUE
CCC
      IF( CLDFG1.EQ.0.0 )  GO TO 70
      IF( IKM .GT. 6 )  GO TO 70
CCC
      DO 68 L=1,NWAVEJ
      R010KJ = 0.0
      R025KJ = 0.0
      R050KJ = 0.0
      R090KJ = 0.0
      R100KJ = 0.0
      DO 66 K=1,NAZI
      R010KJ = R010KJ + R010(K,L)
      R025KJ = R025KJ + R025(K,L)
      R050KJ = R050KJ + R050(K,L)
```

```
      R090KJ = R090KJ + R090(K,L)
      R100KJ = R100KJ + R100(K,L)
   66 CONTINUE
CC         IKM = INDEX FOR ALTITUDES EQUAL TO OR GREATER THAN 12.0 KM
CC         WHEN CLOUDS ARE INCLUDED.
      R010A(IKM,J,L) = FINAZ*R010KJ
      R025A(IKM,J,L) = FINAZ*R025KJ
      R050A(IKM,J,L) = FINAZ*R050KJ
      R090A(IKM,J,L) = FINAZ*R090KJ
      R100A(IKM,J,L) = FINAZ*R100KJ
   68 CONTINUE
CC         STATEMENT 70 IS FOR NADIR LOOP ON INDEX J
   70 CONTINUE
CCC
CC         COMPUTE AVERAGES OVER NADIR ANGLES J AT WAVENUMBERS
CC         L=1,NWAVEJ AND ALTITUDE I.
      FINAD = 1.0/FLOAT(NNADIR)
      DO 74 L=1,NWAVEJ
      SUMM = 0.0
      DO 72 J=1,NNADIR
      SUMM = SUMM + UPRADA(I,J,L)
   72 CONTINUE
      UPRADN(I,L,JBAND) = FINAD*SUMM
   74 CONTINUE
CCC
      IF( CLDFG1.EQ.0.0 )  GO TO 80
      IF( IKM .GT. 6 )  GO TO 80
CCC
      DO 78 L=1,NWAVEJ
      ARCVKJ = 0.0
      R010KJ = 0.0
      R025KJ = 0.0
      R050KJ = 0.0
      R090KJ = 0.0
      R100KJ = 0.0
      DO 76 J=1,NNADIR
      ARCVKJ = ARCVKJ + ARCVA(IKM,J,L)
      R010KJ = R010KJ + R010A(IKM,J,L)
      R025KJ = R025KJ + R025A(IKM,J,L)
      R050KJ = R050KJ + R050A(IKM,J,L)
      R090KJ = R090KJ + R090A(IKM,J,L)
      R100KJ = R100KJ + R100A(IKM,J,L)
   76 CONTINUE
      ARCVN(IKM,L) = FINAD*ARCVKJ
      R010N(IKM,L) = FINAD*R010KJ
      R025N(IKM,L) = FINAD*R025KJ
      R050N(IKM,L) = FINAD*R050KJ
      R090N(IKM,L) = FINAD*R090KJ
      R100N(IKM,L) = FINAD*R100KJ
CCC
CCC        THE GRC VERSION INSERTS THE FOLLOWING RE-SETTING OF UPRADN(I,
CCC        L,JBAND) FOR ALTITUDES .GE. 12 KM AND IF CLOUDS ARE INCLUDED.
CCC              UPRADN(I,L,JBAND) = R050N(IKM,L) + ARCVN(IKM,L)
CCC
   78 CONTINUE
CC         STATEMENT 80 IS FOR ALTITUDE LOOP ON INDEX I
   80 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE VLIN ( X, A, Y, B, Z )                                 VLIN
C                                                                       VLIN
C        *VLIN* FORMS THE LINEAR COMBINATION OF TWO VECTORS.            VLIN
CLJ       SUBROUTINE VLIN RETURNS X(1-3) = A*Y(1-3) + B*Z(1-3).         VLIN
C                                                                       VLIN
      DIMENSION X(3), Y(3), Z(3)                                        VLIN
      X(1) = A * Y(1) + B * Z(1)                                        VLIN
      X(2) = A * Y(2) + B * Z(2)                                        VLIN
      X(3) = A * Y(3) + B * Z(3)                                        VLIN
      RETURN                                                            VLIN
      END                                                               VLIN
```

```
C*  XMIT                                                                XMIT
      SUBROUTINE XMIT ( LX, X, Y )                                      XMIT
C                                                                       XMIT
C        *XMIT* COPIES A CORE BLOCK TO ANOTHER LOCATION.                XMIT
C                                                                       XMIT
CLJ   A GE TEMPO VERSION OF THE GRC ROUTINE XMIT WRITTEN IN COMPASS     XMIT
CLJ   LANGUAGE.                                                         XMIT
CLJ                                                                     XMIT
CLJ   INPUT PARAMETERS                                                  XMIT
CLJ      ARGUMENT LIST                                                  XMIT
CLJ              LX = LENGTH OF ARRAY X                                 XMIT
CLJ               X = THE ARRAY OR CONSTANT TO BE COPIED INTO ARRAY Y.  XMIT
CLJ   OUTPUT PARAMETER                                                  XMIT
CLJ      ARGUMENT LIST                                                  XMIT
CLJ               Y = AN ARRAY, COPIED FROM ARRAY X IF LX.GT.0, AND SET XMIT
CLJ                   TO A CONSTANT X(1) IF LX.LT.0 .                   XMIT
CLJ                   A RETURN OCCURS IF LX.EQ.0 OR IF THE ADDRESS OF X XMIT
CLJ                   EQUALS THE ADDRESS OF Y.                          XMIT
      DIMENSION X(1), Y(1)                                              XMIT
      IF ( LX .LE. 0 ) GO TO 6                                          XMIT
CLJ      LOCF, A FORTRAN INTRINSIC (INTEGER) FUNCTION, OBTAINS THE      XMIT
CLJ      ADDRESS OF A VARIABLE, ARRAY ELEMENT, OR ENTRY POINT OF        XMIT
CLJ      EXTERNAL SUBPROGRAM.                                           XMIT
      IF ( LOCF( X ) - LOCF( Y ) ) 3, 5, 1                              XMIT
    1 DO 2 I=1,LX                                                       XMIT
    2 Y(I) = X(I)                                                       XMIT
      GO TO 5                                                           XMIT
CLJ      THIS BRANCH ALLOWS SHIFTING THE FIRST LX MEMBERS OF ARRAY X TO XMIT
CLJ      START AT SOME MEMBER WHICH LIES WITHIN THE FIRST LX MEMBERS.   XMIT
    3 K = LX                                                            XMIT
      DO 4 I=1,LX                                                       XMIT
      Y(K) = X(K)                                                       XMIT
    4 K = K - 1                                                         XMIT
    5 RETURN                                                            XMIT
    6 IF ( LX .EQ. 0 ) RETURN                                           XMIT
      LXX = -LX                                                         XMIT
      DO 7 I=1,LXX                                                      XMIT
    7 Y(I) = X(1)                                                       XMIT
      RETURN                                                            XMIT
      END                                                               XMIT
```

SECTION 9

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